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THESIS

EVALUATING DEMOGRAPHIC ITEM RELATIONSHIPS WITH SURVEY RESPONSES ON THE MAINTENANCE CLIMATE ASSESSMENT SURVEY (MCAS)

by

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June 2000

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The Maintenance Climate Assessment Survey (MCAS) was developed to proactively assess factors that contribute to a high reliability organization and strong safety climate. The 3rd Marine Air Wing (MAW), which was seeking to proactively improve its safety posture requested the assistance of the School of Aviation Safety at the Naval Postgraduate School to examine its safety climate. Previous studies of the MCAS instrument have focused on the items and their relationship to the HRO based model of safety effectiveness components: process auditing, reward system, quality assurance, risk management, command and control, and communication/functional relationships. The present effort is the first attempt to consider the relationship between item component responses and demographic item responses. It evaluates 893 maintainer responses to the MCAS from 3rd MAW and looks for measurable effects due to demographics. This study finds that the regression models constructed using the demographics as explanatory variables have very little utility in predicting scores for the components. This result allows planners the relief of using the demographics as a low priority issue.

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ABSTRACT

The Maintenance Climate Assessment Survey (MCAS) was developed to proactively assess factors that contribute to a high reliability organization and strong safety climate. The 3rd Marine Air Wing (MAW), which was seeking to proactively improve its safety posture requested the assistance of the School of Aviation Safety at the Naval Postgraduate School to examine its safety climate. Previous studies of the MCAS instrument have focused on the items and their relationship to the HRO based model of safety effectiveness components: process auditing, reward system, quality assurance, risk management, command and control, and communication/functional relationships. The present effort is the first attempt to consider the relationship between item component responses and demographic item responses. It evaluates 893 maintainer responses to the MCAS from 3rd MAW and looks for measurable effects due to demographics. This study finds that the regression models constructed using the demographics as explanatory variables have very little utility in predicting scores for the components. This result allows planners the relief of using the demographics as a low priority issue.

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EXECUTIVE SUMMARY

Naval Aviation is a hazardous undertaking, but in spite of its inherent risk, its Class A Flight Mishap (FM) rate has been cut in half for each decade from 1950 to 1990. Over the last decade, however, the proportion of aircraft losses in which human error has been cited as a contributor has remained relatively constant. To address human factors issues in flight mishaps, the Human Factors Quality Management Board (HFQMB) was established in 1996. By using Mishap Data Analysis (MDA), Organizational Benchmarking (OB), and Command Safety Assessment (CSA), the efforts of the HFQMB resulted in a significant reduction in FM incidence from the perspective of aircrew operations.

Although human error in maintenance is a smaller contributor, it has been shown to be a factor in nearly one in five Class A FMs. To address human error in maintenance, the Human Factors Analysis and Classification System - Maintenance Extension (HFACS-ME) was developed to classify error types in maintenance. Since Naval Aviation is shown to be a high reliability organization (HRO) defined as an organization that operates in hazardous environment with less than its fair share of accidents, it shares common characteristics with other HROs. These common characteristics are outlined in the Model of Organizational Safety Effectiveness (MOSE) and are process auditing, quality, reward system, risk management and command and control. Military aviation has communication/functional relationships as a sixth component. The augmented MOSE is the basis of the Maintenance Climate Assessment Survey (MCAS), which is used to evaluate the organizational safety climate from the perspective of the maintenance

personnel. The MCAS consists of six demographic items and 43 perception items. Each of the 43 perception items maps into a single component of the augmented MOSE. These questions are collapsed into six component scores for each respondent.

Although MCAS has been shown to be an effective tool for evaluating the safety environment in a maintenance organization, demographic factors and their potential relationship with maintainer responses have not been investigated. This study evaluates MCAS responses from 894 maintenance personnel of the 3rd MAW, and looks at how the demographic factors of maintenance personnel might be biasing the component scores of the MCAS. The results of this thesis are intended to further refine MCAS demographic factors and provide Squadron Commanders with insight into the construct of their maintenance personnel.

The component scores are fitted using the demographics as explanatory factors. Univariate analysis is performed for each component using simple models without interaction and also with models using two-factor interactions. These models are then simplified in order to reduce the number of terms to a more manageable level.

The results of this thesis show that up to two-factor interaction, the demographic factors of the MCAS poorly account for the variance in the responses. The reliance on subjective perception in the scoring is the cause of the large amount of variance. Since variance cannot be explained by the demographic factors, the MCAS appears to be demographically unbiased. Input from subject matter experts is used to refine the demographic factors. These revised factors are more usable for Squadron Commanders in that they provide more insight into the make up of the maintenance organization.

LIST OF ACRONYMS

CSA	Command Safety Assessment
FM	Flight Mishap
HFACS	Human Factors Analysis and Classification System
HFACS-ME	Human Factors Analysis and Classification System Maintenance Extension
HFQMB	Human Factors Quality Management Board
HRO	High Reliability Organization
MAG	Marine Air Group
MAGTF	Marine Air Ground Task Force
MAW	Marine Air Wing
MCAS	Maintenance Climate Assessment Survey
MDA	Mishap Data Analysis
MOSE	Model of Organizational Safety Effectiveness
OB	Organizational Benchmarking
SAS	School of Aviation Safety

I. INTRODUCTION

A. OVERVIEW

Naval Aviation is a hazardous undertaking, but in spite of its inherent risk, its Class A Flight Mishap (FM) rate has been cut in half for each decade from 1950 and 1990 (Naval Safety Center, 1997). Class A Mishaps are defined as Naval aircraft incidents resulting in death, permanent disability, or property loss or damage in excess of one million dollars (OPNAV 3750.6Q, 1989). A flight mishap (FM) is defined as those mishaps in which there is $10,000 or greater DoD aircraft damage or loss of a DoD aircraft, and intent for flight for DoD aircraft existed at the time of the mishap. Other property damage, injury, or death may or may not have occurred. Naval Aviation consistently maintains high levels of operability coupled with less than its fair share of accidents (Goodrum, 1999). Naval Aviation also possesses the requisite characteristics of a high reliability organization (HRO): process auditing, reward system, quality, risk management, and command and control. For these reasons, Roberts (1988) labeled Naval Aviation an HRO.

Although Naval Aviation is successful in reducing its Class A FM rate, over the last decade the proportion of aircraft losses in which human error has been cited as a contributor has remained relatively constant at four of five FMs (Naval Safety Center, 2000). In 1996, a Human Factors Quality Management Board (HFQMB) is established after 17 Class A FMs occurred in only 75 days, climaxing when a Navy F-14 crashes into a Nashville, TN neighborhood, to address human factors issues related to mishaps (Nutwell & Sherman, 1997). The goal of the HFQMB is to cut the current Class A FM rate due to human error in half by year 2000 (HFQMB Charter, 1996). The HFQMB adopts three approaches to identify and target factors contributing to human error: 1) Mishap Data Analysis (MDA), 2) Organizational Benchmarking (OB), and 3) Command Safety Assessment (CSA).

MDA establishes the development of HFACS, which is used to identify and prioritize human factors contributors to FMs. Among others, it determines inadequate supervision and aircrew violations are significant contributors (Shappel & Wiegman, 1997). Using OB which explores programs which influence aircrew performance, the HFQMB determines use of feedback mechanisms in commercial airlines improve crew resource management training benefits (Nutwell & Sherman, 1997). Finally, a CSA survey, based on a model of HROs, is developed to determine a command's safety posture from an aircrew perspective. This survey finds that 55% of the Navy respondents and 65% of the Marine Corps respondents feel that their commands are committed beyond what available resources can provide (Ciavarelli & Figlock, 1997). These combined efforts make significant progress toward the HFQMB's goal as evidenced by fiscal year 1999 being the safest year in Naval Aviation history in terms of Class A FM rate.

Maintenance is shown to be a contributing factor in nearly one in five Class A FMs (Naval Safety Center, 2000). Additionally, during FY90-97, Class C FMs account for 75% of all maintenance related mishaps (MRMs). Maintenance is one area where hazards can be controlled and risk can be managed while an aircraft is on the ground. Much work is done in the field of human factors in maintenance safety for commercial airlines ("Human Factors in," 2000). In 1988, the Aviation Safety Research Act (ASRA) mandates close study of aging aircraft structures and human factors affecting safety

("History," 2000). In the spirit of this mandated study, Boeing finds that incomplete installation (34%), damaged on installation (15%), improper installation (11%) and equipment not installed/missing (11%) were the top contributors in maintenance error (Komarniski, 2000). This investigation and classification of types of human error in maintenance leads to the development of Boeing's Maintenance Error Decision Aid (MEDA), a system that aids operators and maintainers in the investigation and mitigation of maintenance related errors (Allen, Rankin, & Sargent, 1998).

The ASRA is one of the precursors for the FAA's current goal to reduce the fatal accident rate 80% by 2007 as compared to 1994-1996 baseline data (FAA, 1998). Several key initiatives are the stepping stones for this ultimate goal: 1) the development of a maintenance resource management system; 2) establishment of new training requirements; 3) implementation of technical advances in aircraft maintenance at repair stations; 4) enforcement of safety recommendations from the National Transportation Safety Board (NTSB); and 5) recommendations for aging systems maintenance. Little work until recently is done for military aviation, and recent efforts involve studying forms of maintenance error (Schmorrow, 1998) and the perceived maintenance safety climate (Baker, 1998). From a proactive perspective, efforts must be made to continue developing assessment tools to identify potential areas for risk management and control of conditions before a mishap occurs.

Using the Maintenance Climate Assessment Survey (MCAS), Goodrum (1999) and Oneto (1999) are able to show the prototype survey effectively evaluates a maintainer's perception of safety in maintenance operations. They also further refine the MCAS into a present 43 question format. One aspect of the MCAS yet to be addressed is the demographic categories to determine their potential relationship with maintainer responses. Given the structure of maintenance organizations within aircraft communities vary, it is unlikely that any pair of samples will have equal proportions of all demographic variables. It is anticipated that individual demographic characteristics may influence MCAS responses and are therefore potentially biasing the results. By understanding the effects of the demographics, one can understand if they impact their organization's safety climate.

B. BACKGROUND

The 3rd Marine Air Wing (MAW) is a combat-ready expeditionary aviation force capable of short-notice worldwide employment to Marine Air Ground Task Force (MAGTF) fleet and unified commanders. It is composed of 28 squadrons divided into four Marine Air Groups (MAGs) based in Southern California and Arizona. Each MAG has its own combat mission: MAG 11 provides air support to MAGTF commanders; MAG-13 provides close-air support, conducts armed reconnaissance, and assumes limited air-defense roles; MAG-16 transports and resupplies Marine air and ground units; and MAG-39 provides utility helicopter support, close-in fire support, fire support coordination, aerial reconnaissance, observation and forward air control in aerial and ground escort operations during ship-to-shore movement and subsequent operations ashore. The aircraft used in these missions are AH-1Ws, UH-1Ns, CH-53s, CH-46Es, F/A-18Ds, F/A-18s, AV-8s and C-130Ts.

From 1990 to 1996, maintenance is a causal factor in 17 percent of all Naval Aviation class A FMs (Naval Safety Center, 1997). From April 1997 to July 1999, maintenance, maintenance personnel or maintenance depot is cited as a causal factor in

14 FMs (eight class C FMs, four class B FMs, and two class A FMs) experienced by 3^{rd} MAW. The Commander of 3^{rd} MAW requests the assistance of the School of Aviation Safety (SAS) at the Naval Postgraduate School, which in turn provides safety and risk management training to personnel, mishap data analysis, and administration of safety climate surveys to help locate problems in the organization.

C. PROBLEM STATEMENT

Human error in aviation is an issue that needs to be addressed, and it is recognized that the organization has an impact on factors that lead to it. Organizations that possess the attributes of a HRO tend to generate environments conducive to the reduction or control of human error and consequently experience fewer mishaps. Organizations aspiring towards the reduction of mishaps need to assess their safety posture as it relates to the attributes of HROs. The School of Aviation Safety at the Naval Postgraduate School has developed surveys to assess HRO characteristics in the operational environment for aircrew and maintenance personnel.

The 3^{rd} MAW in an attempt to improve its safety posture enlists to have the School of Aviation Safety employ the MCAS survey to assess maintainer perception of HRO characteristics in its recent operations. These results are revealing, however in order to provide for better interpretation of the results, an exploration of the demographic variables is in order. This will help commanders to target more effectively specific areas of the organization that require attention.

The current version of the MCAS is administered to the 3^{rd} MAW during the last half of 1999. Using statistical methods, the collected data is analyzed to assess differences in responses that are correlated to differences in demographics. This thesis explores the following questions:

1. Are there measurable demographic effects to the responses on the MCAS?
2. Is there enough information in the demographics to be used in an adjustment process of the overall scores?
3. Can the MCAS be refined further to either collapse or expand demographic factors?

D. SCOPE AND LIMITATIONS

Active duty U.S. Marine Corps Squadrons maintenance personnel of the 3rd MAW are surveyed during the fall of 1999. Only those squadrons with a representative number of respondents are used in the survey. Chapter II provides a basis for understanding human error, organizational safety culture, high reliability organizations and the assessment of a safety climate. Chapter III presents a discussion of the methodology used in this study. Results of data analysis are presented in Chapter IV. Chapter V summarizes previous chapters and provides conclusions and recommendations as they relate to the material.

E. DEFINITIONS

This thesis uses the following definitions (DON, 1989):

Naval Aircraft. Refers to U.S. Navy, Naval Reserve, U.S. Marine Corps, and U.S. Marine Corps Reserve aircraft.

Mishap. A Naval Aviation mishap is an unforeseen or unplanned event that directly involves naval aircraft, which result in $10,000 or greater cumulative damage to naval aircraft or personnel. The mishap is further divided into three classes based on the amount of damage to the aircraft, property and personnel injury. The following are the definitions of the three classes:

a. Class A. A mishap in which the total cost of property damage (including all aircraft damage) is $1,000,000 or greater; or a naval aircraft is destroyed or missing; or any fatality or permanent total disability of a person occurs with direct involvement of naval aircraft.

b. Class B. A mishap in which the total cost of property damage (including all aircraft damage) is $200,000 or more but less than $1,000,000 and/or a permanent partial disability, and or the hospitalization of five or more personnel.

c. Class C. A mishap in which the total cost of property damage (including all aircraft damage) is $10,000 or more but less than $200,000 and/or injury results in one or more lost workdays.

Mishap rate. The total number of Class A,B and C mishaps per 100,000 flight hours.

MCAS. A 43-question survey used to gain insight into the maintenance community's perception concerning aviation mishaps within the Navy and Marine Corps.

HFACS-ME. A taxonomic system used to classify causal factors that contribute to maintenance related mishaps.

HRO. High-Reliability Organization, is an organization that operates in a hazardous environment, yet produces very low rate of accidents and incidents, operating effectively and safely and having the characteristics of leadership, sound management policies, procedure standardization, adequacy of resources and staffing, a defined system for risk management, and other factors.

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II. LITERATURE REVIEW

A. HUMAN ERROR

Reason (1990) defines error as a planned sequence that fails to achieve its intended outcome in the absence of external influence. He (1997) later describes error types as active or latent. Where the effects of active errors are often immediate and confined, latent conditions lie dormant until set off by a chain of local events and can be contributing factors in a variety of failures. This model of latent conditions and active failures is adopted by the Naval Safety Center to investigate Class A FMs with respect to aircrew error, and was the basis for the development of Human Factors Analysis and Classification System (HFACS) (Shappel & Wiegman, 1997).

Activity	'Hands On'	Criticality	Frequency
Normal control	Low	Moderate	High
Emergency control	Moderate	High	Low
Maintenance-related	High	High	High

Table 1. Likelihood of Performance Problems in Given Activities.

Reason (1997) also models human error in the scope of universal human activities (see Table 1) and the likelihood of performance problems within each of these types of activities. With HFACS, the Naval Safety Center is able to address human error in normal control and emergency control conditions. But Reason asserts that maintenance is the area with the highest likelihood of human error because maintenance related activities are almost exclusively reliant on human performance in the three areas of hands on, criticality and frequency. Even with progress in technology, human fallibility remains constant (Reason, 1997) and with the frequency of planned maintenance compounded with the many pairs of fallible human hands working on exceptionally complicated systems, Reason's model is a chilling prediction of 3rd MAW's situation.

To address the maintenance related activity as a contributor to the total of human errors in FMs, Schmidt, Schmorrow and Hardee (1998) extend HFACS to specifically address the maintenance component of accident causation with the HFACS-Maintenance Extension (ME). The HFACS-ME expands upon Reason's model of latent states and psychological precursors to unsafe acts. Reason (1990; 1997) differentiates these latent states in that they create the potential for human error. HFACS-ME classifies latent states in the maintenance environment, with three levels of error causation under four categories of conditions. The first order conditions are broad precursor categories (supervisory conditions, maintainer conditions, working conditions and maintainer acts) that are further divided into more specific precursors to human error of the second and third order (see Table 2).

The causes of human error are many. Wickens, Gordon and Lui (1997) state that human error can be induced by "inattentiveness, poor work habits, lack of training, poor decision making, personality traits, social pressures, and so forth" (p. 427-428). Redmill & Rajan (1997) note that a common component in accidents is a worker's loss of concentration which can be caused by "boredom, disinterest, distraction, or attempt to do two or more things at once" (p.12). Wickens, Gordon and Lui (1997) assert that the most common type of maintenance related error is that of omission. Considering that the nature of planned maintenance is to frequently disassemble, inspect then reassemble components, it is clear to see the high probability of human error in maintenance (Reason

1997). But as Perrow and Reason point out, the errors themselves are seldom isolated, but often a single event in a causal chain (Perrow, 1984), or encouraged, or at least not prohibited from occurring by latent conditions in the organization (Reason, 1997).

First Order	*Second Order*	*Third Order*
Supervisory Conditions	Unforeseen	Hazardous Operations
		Inadequate Documentation
		Inadequate Design
	Squadron	Inadequate Supervision
		Inappropriate Operations
		Failed to Correct Problem
		Supervisory Violation
Maintainer Conditions	Medical	Mental State
		Physical State
		Physical/Mental Limitation
	Crew Coordination	Communication
		Assertiveness
		Adaptability/Flexibility
	Readiness	Preparation/Training
		Qualification/Certification
		Violation
Working Conditions	Environment	Lighting/Light
		Exposure/Weather
		Environmental Hazards
	Equipment	Damaged
		Unavailable
		Dated/Uncertified
	Workspace	Confining
		Obstructed
		Inaccessible
Maintainer Acts	Error	Attention
		Memory
		Rule/Knowledge
		Skill
	Violation	Routine
		Infraction
		Exceptional

Table 2. HFACS-ME Levels of Error Causation.

B. ORGANIZATIONAL SAFETY CULTURE

1. Definition

Organizational culture is defined as shared values and beliefs that interact with an organization's structures and control systems to produce behavioral norms (Uttal, 1983). All organizations have their own engineered culture whether good or bad. A safety culture is ideal for complex organizations and is defined as the product of individual and group values, attitude, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety programmes (Booth, 1993).

2. Composition

Redmill and Rajan (1997) state that there are three general aspects of safety culture: awareness, commitment and competence. Awareness must be present in all aspects of design, management and decision making. When a safety mishap does occur, it is commitment that drives the leadership of the organization to investigate and locate contributing factors and take immediate action to prevent another occurrence. Competence is a combination of education, training, professionalism and personality traits that are appropriate for a given task or job (Redmill & Rajan, 1997).

Reason (1997) prefers the term *informed culture*, and he divides informed culture into four subcultures: *reporting culture, just culture, flexible culture* and *learning culture*. Reporting culture is "an organizational climate in which people are prepared to report their errors and near-misses." Just culture is an "atmosphere of trust in which people are encouraged, even awarded, for provided essential safety-related information – but in which they are also clear about where the line must be drawn between acceptable and unacceptable behavior." Flexible culture involves "shifting from the conventional hierarchical mode to a flatter professional structure, where control passes to task experts on the spot, and then reverts back to the traditional bureaucratic mode once the emergency has passed. Such adaptability is an essential feature of the crisis-prepared organization." Learning culture is "the willingness and the competence to draw the right conclusions from its safety information system, and the will to implement major reforms when their need is indicated."

Safety culture has powerful effects. First, it is self perpetuating where workers learn from each other and encourage each other to work in a manner consistent with the organization's safety culture. People are quick to follow the example of coworkers, even if this means a lack of vigilance in safety (Redmill & Rajan, 1997). Wogalter, Allison, & McKenna (1989) assert that "people are extremely susceptible to social norms; they are likely to engage in safe or unsafe behaviors to the extent that others around them do so." Safety culture is also self preserving as new workers learn to identify acceptable methods of accomplishing work and are able to pass those standards along to new employees, good or bad (Redmill & Rajan, 1997).

C. HIGH RELIABILITY ORGANIZATIONS

1. Definition

Roberts (1990) and Libuser (1994) explain that High-Reliability Organizations (HROs), organizations that operate in a hazardous environment, yet produce very low rates of accidents and incidents, which operate effectively and safely have certain key characteristics in common. Reason (1997) calls them organizations with less than their fair share of accidents, and "highly complex, technology-intensive organizations that must operate, as far as humanly possible, to a failure-free standard." He also explains that HROs manage complex technologies that have very low tolerance for error, yet maintain the flexibility to successfully function in environments of extreme intensity.

2. Characteristics of HROs

Examples of HROs are the nuclear power industry, petrochemical industry, and airline industry. Additionally, Figlock (1998) identifies Naval aviation is an HRO. Although diverse in purpose, Roberts and Libuser believe these organizations share several common characteristics: leadership style, management policies, procedures standardization, superior training, a reward system that recognizes safety achievement, adequacy of resources and staffing, effective management of risks associated with hazardous operations, and other factors.

HROs have a requisite variety. As Weick (1987) states, having diverse people from diverse backgrounds and experiences builds requisite variety that is required for relatively simple humans to operate complex systems. Additionally, this diversity is essential in problem solving, as individuals will approach the same problem uniquely, so that the collective contribution is greater than any one individual's input.

HROs typically exhibit a high degree of training. Weick (1987) notes that "training for the operation of high reliability systems is often tough and demanding so that the faint of heart and the incompetent are weeded out." This is because HROs are not afforded the luxury of trial and error. Training is often in the form of simulation and stories. Stories have a big affect on the reliability of an HRO by lending experience to the inexperienced:

> The basic idea is that a system which values stories, story tellers, and storytelling will be more reliable than a system that derogates these substitutes for trial and error. A system that values stories and storytelling is potentially more reliable because people know more about their system, know more of the potential errors that might occur, and they are more confident that they can handle those errors that do occur because they know that other people have already handled similar errors (Weick, 1987, p. 113).

By sharing the experiences of skilled personnel, novices do not have to learn from their own mistakes and are also granted the insight of the skilled.

HROs appear bureaucratic and uneventful on the surface. There is a strict chain of command in place that dictates policy, procedure and environment. This strong centralization is apparent during periods of relatively low intensity, but as intensity of operating increases, the true nature of the HRO is revealed, where flexibility, delegation, improvisation and technical expertise dominate (Reason, 1997; Weick, 1987). This is how HROs can be simultaneously centralized and decentralized. Responsibility and judgment remain centralized while creativity, improvisation and unsupervised problem solving become decentralized in environments of high intensity (Weick, 1987).

Reliability in HROs is another deceptive aspect. Weick (1987) calls reliability a "dynamic non-event," meaning a great deal of effort goes into ensuring nothing happens. This dynamicism is based on the belief that reliability is fleeting and systems tend to move to states of unreliability unless constantly maintained:

> Part of the mindset for reliability requires chronic suspicion that small deviations may enlarge, a sensitivity that may be encouraged by a more dynamic view of reliability (Weick, 1987, p. 119).

It is the organizational culture for personnel to look for problems before they happen. Weick continues that because of the invisibility of the dynamics behind reliability, there is a perception that reliability is easily achievable and is only noticed in the presence of a breakdown.

D. ASSESSING SAFETY CLIMATE

1. Safety Space

Reason (1997) states that organizations can be mapped into a safety space which is a continuum of degrees of susceptibility to accidents (see Figure 1). Organizations with higher resistance will generally have fewer mishaps while organizations with higher vulnerability will generally experience more mishaps. No organization is immune. Chance, unforeseen circumstances, failures in defenses and human error can cause even the most resistant organizations to experience accidents. Within the safety space, currents tend to push organizations away from the extremes of resistance or vulnerability and toward the center, a compromise between the two. If an organization has the desire to become more resistant, it must swim upstream.

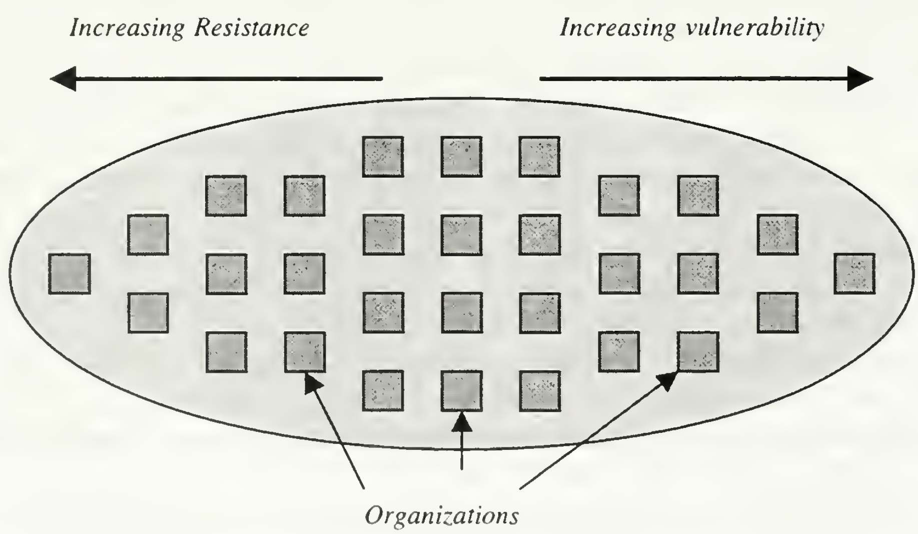

Figure 1. Organizational Safety Space.

The effort required to move in the direction of increased resistance must be put into reactive and proactive measures. Reason (1997) contends that investigating mishaps to find causal factors to be addressed is not even half the battle. To effectively move the organization, mishap investigation must be coupled with the identification of conditions needing correction, and regular checks.

2. MOSE and MCAS

Libuser's (1994) current Model of Organizational Safety Effectiveness (MOSE) is based on work by Roberts and is a categorization of the common characteristics of HROs. These characteristics are mapped into five components: 1) Process Auditing (PA) - checks by members to identify hazards; 2) Reward System (RS)- expected rewards or disciplinary action used to shape behavior; 3) Quality Assurance (QA)- promotion of quality performance; 4) Risk Management (RM)- system to identify hazards and control operational risks; and 5) Command and Control (CC)- safety climate, leadership effectiveness /policies, and procedures for mitigating risks. These components are very similar to the aspects of Reason's (1997) informed culture (Table 3).

Libuser's MOSE Components	*Reason's Informed Culture*
Process Auditing (PA)	Leaning Culture
Reward System (RS)	Just Culture
Quality Control (QA)	Reporting Culture
Risk Management (RM)	Flexible Culture
Command and Control (CC)	Flexible Culture

Table 3. Comparison of Libuser's MOSE and Reason's Informed Culture.

Ciavarelli and Figlock (1997) adapt the MOSE for use in Naval Aviation using practices and terminology of that environment and develop the Command Safety Assessment, a survey that addresses each of the MOSE categories from the viewpoint of the aircrewman. This survey is administered to 1,254 aviators revealing that organizational and supervisory issues are seen by aircrewmen as impacting flight safety.

The Maintenance Climate Assessment Survey (MCAS) is the product of the implementation of the MOSE and CSA in a maintenance context. Baker (1998) starts by reducing 155 candidate questions to 67 items that specifically addressed aviation maintenance. Augmenting Libuser's (1994) five category MOSE model with a sixth category, Communication/Functional Relationships, Baker (1998) modifies the CSA to look at aviation safety from the point of view of the maintenance person. Using regression techniques, Baker is able to further reduce the survey into a compact 35 item form, with almost all questions mapped to a single category of the augmented MOSE.

Goodrum (1999) and Oneto (1999) show that the MCAS is a valid tool to accurately assess an aviation maintenance environment, but note that some items in the survey need restructuring. Oneto notes that these items address more than one category of the MOSE. Their inputs help change the MCAS to its current 43 item format (see Appendix A). While Goodrum and Oneto are able to show content validity in the MCAS, there is much left to examine. Since there is no known or accepted measure for MCAS results and providing feedback to the concerned squadrons, an effort is underway to explore concurrent validity in the survey on a per question basis (Schmidt, personal communication). Questions that have a low response mean are noted as areas that need attention, corresponding to a particular category of the MOSE, and which part of the HRO needs closer examination.

Additionally, by looking at squadron mean scores to the survey and available mishap data, Harris (personal communication) is looking at the MCAS predictive validity in the incidence of mishaps within a squadron based on adjusted mean scores. While the work by Harris seeks to broaden the scope and applicability of the MCAS, this study explores internal aspects of the survey. By separating responses by demographics, this thesis will further explore the attitude of the Naval aviation maintenance person with respect to safety.

3. Instrument Design and Demographics

The design of the MCAS is a cross-sectional one time look at a maintenance organization (see Appendix A). It is a self-administered questionnaire that polls respondent perception about the safety of their working environment at all levels. Demographic items preserve anonymity by excluding personal questions which could be linked to individuals allowing personnel the freedom to express their true opinion to the perception items (Oneto, 1999).

Though there are many methods for data collection from people, surveys, when designed properly, are very effective for recording respondent scores based on a particular model (Fink & Kosecoff, 1985). MCAS responses are forced using a five point Likert scale (see Appendix A). Using a forced scale instead of subjective comments allows for rapid compilation of data and analyzation of responses as numerical values, which is convenient for numerical scoring and comparisons of scores between respondents, or groups of respondents (Fink & Kosecoff, 1985). The grouping is facilitated by the six demographic items of the survey (Baker, 1998). By being able to group types of maintainers independent of their scores, it is possible to investigate for unequal perceptions across demographic groups.

The demographic items in the MCAS capture aspects of the maintainer within the organization such as experience, and rank, and ignore personal information such as age, race, sex and ethnicity (Baker, 1998). Although it would be difficult to capture every possible combination of demographic factors, the MCAS is able to capture most job types from most aircraft communities. Each of the demographic line items in the MCAS represents a simple factor that might influence the scoring. It is unknown which of these demographics constitutes a valid or invalid factor.

E. SUMMARY

HROs are complex and dynamic by nature but are not impervious to unsafe trends in human performance. Perrow (1984) points out that regardless of an organization's structure and nature, "normal accidents" will continue to occur. With HROs, these accidents tend to occur less frequently, but the consequences of the accidents tend to be large in magnitude. These organizations must put effort into swimming upstream through Reason's safety space towards increased resistance to accidents. This happens through reactive measures like mishap analysis and proactive measures to identify "pathogenic conditions" (Reason, 1997). Though reactive measures are in place, proactive measures are coming up to speed.

Two critical parallel developments in organization safety theory in regards to aviation safety are the development of effective taxonomies (e.g., HFACS-ME) and the identification and accurate modeling of HROs (e.g., augmented MOSE). The development of CSA and MCAS are steps to link the taxonomies and the organization models. Since MOSE parallels Reason's informed culture, it is possible with MCAS to identify those conditions that are not conducive to safety and take proactive measures to move the organization towards increased resistance to accidents in the safety space. Since 3rd MAW is a HRO, CSA and MCAS allow for the identification of the MOSE components that require attention.

The MCAS has been revised into a more usable form, and has been validated, showing that the individual items do address specific MOSE components. This thesis is another step into revising the MCAS further by looking at the validity of the demographic factors. Mapping the demographic factors into the MOSE component scores will show if the factors are relevant or can be removed from the survey. Additionally, if these factors do not account for the variance in scores, the survey is not asking the correct demographic questions and will require further revision.

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III. METHODOLOGY

A. RESEARCH APPROACH

The intent of this study is to assess the maintainer's perception of safety in his or her work environment. This research involves the use of analysis techniques to partition the collected data into smaller groups based on demographics then investigate differences in responses among the groups. If statistical differences are found, a comparison between the group mean and a particular squadron mean shows how a particular demographic differs from the rest of the squadron. Conversely, it shows which demographics have response means that are more reflective of the squadron means.

B. DATA COLLECTION

1. Subjects

Surveys are administered to 977 officers and enlisted personnel responsible for Naval Aviation maintenance. These subjects come from squadrons and maintenance units of the 3rd Marine Air Wing located at MCAS Miramar, CA, Camp Pendleton, CA, and MCAS Yuma, AZ. The aircraft represented are the AH-1 "Super Cobra," UH-1 "Huey," CH-53 "Super Stallion," CH-46E "Sea Knight," F/A-18D "Night Attack Hornet," F/A-18 "Hornet," AV-8B "Harrier," and the C130T "Hercules."

Additionally, subject matter experts are interviewed about what they consider to be important demographic information about the personnel in their maintenance organizations. Subject matter experts are military aviators with at least eight years active duty service. The results of these interviews are given in the next section.

2. Instrument

The MCAS is a self-administered, group survey consisting of two parts: 1) demographics: 2) perception. Part I captures demographic factors of each subject: community, squadron, rank, years of aviation maintenance experience, work center, and shift. There are eight choices available for community, with an additional option of "other." The squadron factor records the three-digit squadron designator. Embedded in these two factors is aircraft type (seventh factor). Rank is divided into four levels of enlisted personnel and three levels of officer personnel. Years of aviation maintenance experience is partitioned into seven levels. Work center or shop, is divided into eight shops with the option of "other." Shift divides subjects into dayshift or nightshift.

Part II captures subject perception of his or her work environment. There are 42 items, each of which is mapped into a single augmented MOSE component: process auditing (six questions), reward system (eight questions), quality assurance (six questions), risk management (nine questions), command and control (eight questions), and communication/functional relations (six questions). Each perception item asks subjects to rank a specific safety related activity or aspect of their organization using a five point Likert rating scale with verbal anchors as follows: Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree. When completed, the items for each MOSE component are averaged to attain six composite scores, each one corresponding to the subject's rating of that particular augmented MOSE component for his or her organization.

3. Procedure

The survey is administered on site and in a group setting at the various participating Squadrons of the 3rd MAW. Additionally, the survey is given in conjunction with a scheduled maintenance safety presentation on human factors issues in aviation. The Squadrons are in various stages of training and operational tasking at the time of the survey being administered. The variety of operational tasking with which the squadrons are simultaneously involved during the administration of the MCAS accounts for much of the variance in the number of surveys collected from each squadron. Potential MCAS respondents are briefed on maintenance issues, the survey and its purpose and questions that arise pertaining to the survey are answered by the survey administer. Respondents fill out the surveys using scannable computer forms. The surveys are then immediately collected upon completion to allow for maximum accountability.

For personal interviews, subject matter experts report what they think are the important factors when considering the demographics of personnel in their maintenance organizations. Notes are taken during these interviews and a list is compiled from the responses of the personnel interviewed. This list represents potential MCAS demographic items.

C. DATA ANALYSIS

1. Data Tabulation

Survey results were compiled into a database using a scanning machine, then imported into Microsoft Excel. The spreadsheet consists of rows of respondents and columns of survey items (both demographic and survey items). Demographic items record mainly bivariate and multivariate responses, such as squadron (aircraft type embedded), rank, and years experience. Survey item responses were assigned a numerical value of 1 through 5 corresponding to the Likert scale, with higher values being assigned to more positive responses (strongly agree) and lower values assigned to more negative responses (strongly disagree). Each of the questions in the survey addresses one of the six MOSE components. Items addressing similar MOSE components were collapsed into an average score for that particular component. Any items that were missing values were excluded and not averaged into the component score. No weighting is assigned to items in the event of a missing item score. The three demographic response items corresponding to the respondent's squadron number were collapsed into a single coded value.

2. Statistical Analysis

Microsoft Excel is used to provide summary statistics and initial familiarization with the data. The data were cleansed by removing subject responses with omitted demographic items leaving 894 responses. Items corresponding to augmented MOSE components were averaged for each respondent, leaving six scores along with demographic response items. If subjects omitted a perspective item response, the component score is averaged for the completed items of that component. No weighting for omitted perspective items is administered. Histograms of the demographic make up of the data are constructed. The data are then exported to ARC for its powerful graphing capabilities. Initial scatterplot matrices of each component over all demographic factors revealed no linear, exponential, or power trend, although scatterplots matrices of the components over themselves revealed a linear trend.

The data are then transported to MathSoft S-plus for analysis. Categorical demographics are coded as factors and the aov function is implemented to fit the six component scores based on demographic factors. Six models (one for each component) are constructed for a regression without interaction among factors. Six additional models are fit for a regression looking at two factor interaction. Each model is then simplified by using S-plus to remove unimportant terms. Models are compared and similar models for some of the components are found. Three term interaction models are not explored in this thesis.

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IV. RESULTS

A. SIMPLE MODELS WITHOUT INTERACTION

A scatterplot matrix is constructed to see if there are any trends in the data. This is done without designating the independent variables as factors. The scatterplot shows that there is some relationship between the component scores, but little information about the demographics is revealed. Figure 3 is a scatterplot matrix for PA versus each of the demographic factors. Visual inspection reveals a possible relationship between PA and Rank and Total years of Aviation experience.

Figure 1. Scatterplot of PA versus Demographic Factors.

Three dimensional bar plots for the components versus each factor are constructed to see if there are any visual clues as to some type of relationship between the factors and the response. No linear, log linear or exponential relationship is visible. However, the plots seem compatible with those of normally distributed histograms for each level of factor, all centered in the same approximate region of the component score (e.g. Figure 4).

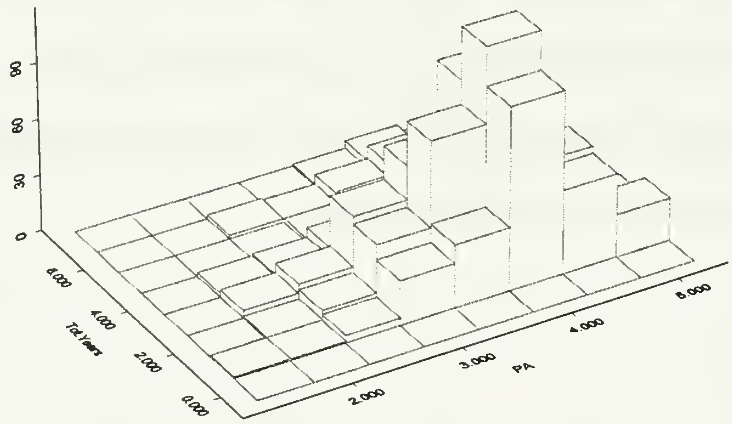

Figure 2. Three Dimensional Bar Plot of PA Scores. PA scores are plotted against different levels of Total Years of Aviation Maintenance Experience.

Since there is no indication that a transformation of the data is required due to visible trends, linear models for the six individual components are fit against untransformed factors without interaction using the aov function in S-plus. Model checking plots are constructed and case 219 is shown to have very high influence in all models. Case 219 is an E-6/7 with 15-20 years of aviation maintenance experience, works the day shift in “other” work center, in a VMH squadron. Although there is no significance test associated with Cook’s Distance, case 219 is deleted from the data set due to its unusually high influence and new models were fit (see Appendix C).

Model checking plots are constructed to check the fit of the models with case 219 removed. The scatter plot of the data with the regression superimposed reveals what might be a slight upward trend in the response for all components (see Appendix D). The histograms of the residuals show that the distribution of the residuals appear to be normal (see Appendix E), and the scatterplot of the residuals versus the fitted values shows no discernable pattern in the residuals (see Appendix F). The QQ-plot shows that the residuals are thin at both tails for all models (see Appendix G), but the normal shape is tenable.

Component	R^2	$\hat{\sigma}$
PA	0.1095	0.5529
QA	0.1219	0.6327
RS	0.1427	0.5896
RM	0.1869	0.5690
CC	0.1280	0.6349
CR	0.1233	0.6846

Table 4. R-squared and $\hat{\sigma}$ for Models without Interaction.

Values for the coefficient of determination, R^2, show that these models account but poorly for the variance in the data. The best model is RM, accounting for less than 19% of the total variance (see Table 4). The model with the lowest R^2 is PA with only 11% of the total variance explained. Values for standard error, $\hat{\sigma}$, indicate that there is a large spread in the response values. For example, with a perfect R^2 of 1, the model for PA tells us that 68% of the respondents score between 3.31 and 4.42, and that 96% score between 2.76 and 4.97. Since the only possible scores are between 1 and 5, relatively high values for $\hat{\sigma}$ are not much help with understanding the data.

The results from the analysis of variance from each model causes rejection of the null hypothesis that all of the coefficients in the model are zero, accepting the alternate hypothesis that at least one coefficient is not equal to zero (see Appendix H). Additionally, the models for PA, CC and CR fail the lack of fit test indicating that the shape of the fit is not correct. These models do not do well in describing the data.

B. MODELS WITH TWO FACTOR INTERACTION

Two-factor interaction models are constructed for all of the components using S-plus to see if more of the variance in the data can be modeled and model checking plots are constructed. The scatterplot of the data with the superimposed regression shows a linear trend in the response against the factors (see Appendix I), and the distribution of the residuals appears to be normal (see Appendix J). The scatterplot of the residuals versus the fitted values shows no discernable pattern in the residuals (see Appendix K). The QQ-plots show strange behavior at values close to zero, but that they are close to being normal for all components (see Appendix L). R^2 and $\hat{\sigma}$ are given in Table 5.

These two term interaction models are better at explaining more of the variance in the data as indicated by the values for the coefficients of determination, however there is very little reduction in the values for the standard error. This improvement in the values for R^2 comes at the cost of increased complexity in the models. While the models without interaction have 43 terms, the two term interaction models have 343 terms. By adding 300 terms to the model, 300 degrees of freedom are lost resulting in no significant improvement in the standard error.

Component	R^2	$\hat{\sigma}$
PA	0.4813	0.5246
QA	0.4832	0.6034
RS	0.5046	0.5572
RM	0.5207	0.5431
CC	0.4968	0.5996
CR	0.4850	0.6523

Table 5. R^2 and $\hat{\sigma}$ for Two Factor Interaction Models.

Analysis of variance on the two factor interaction models causes rejection of the null hypothesis that all of the coefficients are equal to zero. The alternative hypothesis is accepted meaning that at least one coefficient is not equal to zero. Present in the anova tables is evidence that some of the terms are not necessary in the model and that simplification is possible.

C. REDUCED MODELS WITHOUT INTERACTION

The step function in S-plus is used to subtract terms from the simple models in an effort to simplify the models without losing too much of the information they provide. S-plus accomplishes this by using Akaike's information criterion which is of the form:

$$AIC = -2log\mathrm{L}(x_{m+1}, \ldots, x_n \mid x_1, \ldots, x_m) + 2r$$

where r is the total number of estimated parameters. The AIC is a value that penalizes a model for having high complexity when compared to simpler models with fewer terms.

The step function is applied to the simple models without interaction and the results are given in Appendix N. The reduced models have between 15 and 33 terms compared to 43 terms for the original models. Model checking plots are constructed with no significant graphical differences between the reduced simple models and the simple models (see Appendices O-R). Values for the coefficient of determination and standard error are given in Table 6. As expected, less of the total variance is explained by the reduced models, and the value for $\hat{\sigma}$ increases.

Component	R^2	$\hat{\sigma}$
PA	0.0915	0.5532
QA	0.1002	0.6345
RS	0.1240	0.5925
RM	0.1703	0.5711
CC	0.1071	0.6365
CR	0.0784	0.6906

Table 6. R^2 and $\hat{\sigma}$ for Reduced Models without Interaction.

D. REDUCED TWO FACTOR INTERACTION MODELS

The step function in S-plus is applied to the two factor interaction models and the results are given in Appendix S. The data were fit to the new models and model checking plots are constructed and given in Appendices T-W. The scatterplot of the data with the superimposed regression line indicates that there might be a linear relationship between the factors and the score, but most of the data looks like a point cloud. The histograms of the residuals have the appearance of a normal distribution. The predicted values versus the residuals have no pattern and the QQ-plots look normal.

The reduced models have significantly decreased values for R^2 with little change in values for $\hat{\sigma}$. These models use between 33 and 59 terms which is a significant simplification over the 343 term models, but a lot of the explanation of the total variance is lost in the transition. Table 6 summarizes R^2 and $\hat{\sigma}$ for the reduced models.

Component	R^2	$\hat{\sigma}$
PA	0.1098	0.5496
QA	0.1228	0.6287
RS	0.1854	0.5802
RM	0.2453	0.5534
CC	0.1747	0.6225
CR	0.1342	0.6779

Table 7. R^2 and $\hat{\sigma}$ for Reduced Two Factor Models with Interaction.

E. COMPARING MODELS

The S-plus anova function is applied to pairs of models to see if they are statistically different. The results are given in Appendix U. At $\alpha = 0.05$, eight pairs of models were found to be statistically similar, with the highest similarity between simple and reduced two term interaction models for PA and QA (p-Value > 0.99). Most of the model pairs are statistically different.

Choosing the most appropriate model for a complex data set is compromise between a model that explains enough of the data while being simple enough to use. The two factor interaction models are too complicated to be practical with 343 terms. The rest of the models are not different enough to distinguish in practice, so the models with the fewest terms are the preferred models, which in this case are the reduced simple models. Realistically, none of the models are useful. Not enough of the total variance in the data is explained nor is the range of expected scores reduced to a useful level.

F. INTERVIEWS

Subject matter experts interviewed agree that while all of the factors in the survey are important, additional factors could be added to more effectively group personnel and provide more information about the maintenance organization. They also think that dividing total years of aviation maintenance experience into two items, years worked in MOS and years worked outside of MOS is necessary to clarify that Total years of aviation maintenance experience is not simply time on active duty. The experts also indicate factors that look at levels of education and training and levels of morale and motivation are important and should be included in the demographic items of the survey. Responses from subject matter experts are given in Appendix Y.

V. CONCLUSIONS

A. FINDINGS

The results of this thesis show that at the first level of interaction, the demographic factors of the MCAS poorly account for the variance in the responses. The models constructed using linear regression and analysis of variance do not capture the responses of the surveyed population, showing that the demographic factors have low utility in data analysis. While analysis of variance shows that the models are preferred to no model at all, in use the models are too complex and do not provide enough insight into the surveyed group.

Since the component scores are subjective perceptions, there is no correct score to any of the perception items. The reliance on the human component in the scoring is the cause of the large amount of variance, and since variance cannot be explained by the demographic factors, the MCAS appears to be demographically unbiased. The three dimensional bar plots of the component scores versus the levels of factors seem to support this (see Figure 4). Either the MCAS has insignificant biasing across factors or the present factors do not correctly group respondents to allow the biasing to be conclusively measured.

Although the demographics do not effectively group respondents, they do provide information about the demographic composition of the surveyed group. This information alone can be useful to commanders in understanding the substance of their squadrons. To make these items more useful, changes to the MCAS demographic items based on the responses from subject matter experts are recommended below.

B. RECOMMENDATIONS

With the MCAS moving to the internet, it will be possible to use more demographic factors than what is currently constrained by the layout of scannable computer response sheets. The MCAS demographic items should be changed to include the following items:

1) Check the box corresponding to your community:

2) Type in your unit number.

3) Type in the number of months have you been with your current squadron.

4) Type in the total number of maintenance activities to which you have been assigned.

5) Type in the number of deployments you have made.

6) Check the box corresponding to your rank.

7) Type in the number years have you worked in your MOS.

8) Type in the number of years have you worked outside of your MOS.

9) Type in any supervisory designations that you hold.

10) Check the box corresponding to your work center.

11) Check the box corresponding to your shift.

12) Have you attended A School?

With these new questions, further analysis can be conducted to investigate for valid factors that properly describe the data in the responses, in addition to investigating if personal performance makes a difference in scoring. Additionally, MCAS could be modified to gauge safety climates in other military activities such as military ordnance handling facilities and flight deck operations by adjusting the demographic items to suit those specific activities.

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APPENDIX A. 43-ITEM MAINTENANCE CLIMATE ASSESSMENT SURVEY

MAINTENANCE CLIMATE ASSESSMENT SURVEY (MCAS)

Purpose: The MCAS was designed to capture maintainer perceptions of maintenance operations as they relate to safety. Your responses help guide Naval Aviation's on-going efforts to reduce aviation related mishaps. Thank you in advance for your participation!

Directions: Do not write on this form. Fill in all of your responses using the computer sheet provided. Fill in each box that corresponds to your response completely using a pencil. This is not a timed event, so answer each question carefully and honestly. Individual responses will not be reported, only compiled results will be provided to each squadron.

Part I- Demographics has six items requesting unit and biographical data. This information will aid in the response analysis. NO attempts will be made to identify individuals.

Part II- Perceptions has 43 questions pertaining to the maintenance operations. Please choose the response to each item that most correctly reflects your honest opinion. Responses are:

A- Strongly Agree B- Agree C- Neutral D- Disagree E- Strongly Disagree

Part I- Demographics

Line 1 — Fill in the numbered circle corresponding to your community?
(1) VMGR (2) VMA (3) VMFA (4) HMT (5) HMM
(6) VMAQ (7) HMH (8) VMH (9) Other

Line 2-4 — Fill in the circles corresponding to your squadron number

Line 5 — Fill in the numbered circle corresponding with you rank
(1) E1-3 (2) E4-5 (3) E6-7 (4) E8-9 (5) WO1-4 (6) O1-03 (7) O4-5

Line 6 — Fill in the numbered circle corresponding to your total years of Aviation Maintenance experience
(1) <1 (2) 1-2 (3) 3-5 (4) 6-10 (5) 11-15 (6) 15-20 (7) 20+

Line 7 — Fill in the numbered circle corresponding to your work center
(1) Power Plants (2) Airframes (3) Survival (4) Quality Assurance
(5) Ordnance (6) Avionics (7) MAINT Control (8) Line (9) Other

Line 8 — Fill in the numbered circle corresponding to your shift
(1) Day (2) Night

Part II Perceptions
Fill in the lettered circle that corresponds with your response to each item.

	SA	A	N	D	SD
1. The command adequately reviews and updates safety.	(A)	(B)	(C)	(D)	(E)
2. The command monitors maintainer qualifications and has a program that targets training deficiencies.	(A)	(B)	(C)	(D)	(E)
3. The command uses safety and medical staff to identify/	(A)	(B)	(C)	(D)	(E)

manage personnel at risk.

	SA	A	N	D	SD
4. CDIs/QARs routinely monitor maintenance evolutions.	(A)	(B)	(C)	(D)	(E)
5. Tool control is taken seriously in the command and support equipment licensing is closely monitored.	(A)	(B)	(C)	(D)	(E)
6. Signing off personnel qualifications are taken seriously.	(A)	(B)	(C)	(D)	(E)
7. Our command climate promotes safe maintenance.	(A)	(B)	(C)	(D)	(E)
8. Supervisors discourage SOP, NAMP, or other procedural violations and encourage reporting safety concerns.	(A)	(B)	(C)	(D)	(E)
9. Peer influence discourages SOP, NAMP, or other violations and individuals feel free to report them.	(A)	(B)	(C)	(D)	(E)
10. Violations of SOP, NAMP, or other procedures are not common in this command.	(A)	(B)	(C)	(D)	(E)
11. The command recognizes individual safety achievement through rewards and incentives.	(A)	(B)	(C)	(D)	(E)
12. Personnel are comfortable approaching supervisors about personal problems/illness	(A)	(B)	(C)	(D)	(E)
13. Safety NCO, QAR, and CDI, are sought after billets.	(A)	(B)	(C)	(D)	(E)
14. Unprofessional behavior is not tolerated in the command	(A)	(B)	(C)	(D)	(E)
15. The command has a reputation for quality maintenance and sets standards to maintain quality control.	(A)	(B)	(C)	(D)	(E)
16. QA and Safety are well respected, and are seen as essential to mission accomplishment.	(A)	(B)	(C)	(D)	(E)
17. QARs/CDIs sign-off after required actions are complete and are not pressured by supervisors to sign-off.	(A)	(B)	(C)	(D)	(E)
18. Maintenance on detachments is of the same quality as that at home station.	(A)	(B)	(C)	(D)	(E)
19. Required publications/tools/equipment are available, current/serviceable, and used.	(A)	(B)	(C)	(D)	(E)
20. QARs are helpful, and QA is not "feared" in my unit.	(A)	(B)	(C)	(D)	(E)
21. Multiple job assignments and collateral duties adversely affect maintenance.	(A)	(B)	(C)	(D)	(E)

	SA	A	N	D	SD
22. Safety is part of maintenance planning, and additional training/support is provided as needed.	(A)	(B)	(C)	(D)	(E)
23. Supervisors recognize unsafe conditions and manage hazards associated with maintenance and the flight-line.	(A)	(B)	(C)	(D)	(E)
24. I am provided adequate resources, time, personnel to accomplish my job.	(A)	(B)	(C)	(D)	(E)
25. Personnel turnover does not negatively impact the command's ability to operate safely.	(A)	(B)	(C)	(D)	(E)
26. Supervisors are more concerned with safe maintenance than the flight schedule, and do no permit cutting corners.	(A)	(B)	(C)	(D)	(E)
27. Day/Night Check have equal workloads, and staffing is sufficient on each shift.	(A)	(B)	(C)	(D)	(E)
28. Supervisors shield personnel from outside pressures and are aware of individual workload.	(A)	(B)	(C)	(D)	(E)
29. Based upon my command's current assets/manning it is not over-committed.	(A)	(B)	(C)	(D)	(E)
30. My command temporarily restricts maintainers who are having a problems.	(A)	(B)	(C)	(D)	(E)
31. Safety decisions are made at the proper levels and work center supervisor decisions are respected.	(A)	(B)	(C)	(D)	(E)
32. Supervisors communicate command safety goals and are actively engaged in the safety program.	(A)	(B)	(C)	(D)	(E)
33. Supervisors set the example for following to maintenance standards and ensure compliance.	(A)	(B)	(C)	(D)	(E)
34. In my command safety is a key part of all maintenance operations, and all are responsible/accountable for safety.	(A)	(B)	(C)	(D)	(E)
35. Safety education and training are comprehensive and effective.	(A)	(B)	(C)	(D)	(E)
36. All maintenance evolutions are properly briefed, supervised, and staffed by qualified personnel.	(A)	(B)	(C)	(D)	(E)
37. Maintenance Control is effective in managing all maintenance activities.	(A)	(B)	(C)	(D)	(E)
38. Good communication exists up/down the chain of command.	(A)	(B)	(C)	(D)	(E)
39. I get all the information I need to do my job safely.	(A)	(B)	(C)	(D)	(E)

		SA	A	N	D	SD
40.	Work center supervisors coordinate their actions.	(A)	(B)	(C)	(D)	(E)
		SA	A	N	D	SD
41.	My command has effective pass-down between shifts.	(A)	(B)	(C)	(D)	(E)
		SA	A	N	D	SD
42.	Maintenance Control troubleshoots/resolves gripes before flight.	(A)	(B)	(C)	(D)	(E)
		SA	A	N	D	SD
43.	Maintainers are briefed on potential hazards associated with maintenance activities.	(A)	(B)	(C)	(D)	(E)

APPENDIX B. MODEL OF SAFETY EFFECTIVENESS COMPONENTS.

COMPONENT 1: PROCESS AUDITING

1. The command adequately reviews and updates safety practices.
2. The command monitors maintainer qualifications and has a program that targets training deficiencies.
3. The command uses safety and medical staff to identify/manage personnel at risk.
4. CDIs/QARs routinely monitor maintenance evolutions.
5. Tool Control is taken seriously in the command and support equipment licensing is closely monitored.
6. Signing personal qualifications are taken seriously.

COMPONENT 2: Reward System and Safety Climate

1. Our command climate promotes safe maintenance and flight operations.
2. Supervisors discourage SOP, NAMP or other procedure violations and encourage reporting safety concern.
3. Peer influence discourages SOP, NAMP or other violations and individuals feel free to report them.
4. Violations of SOP, NAMP or other procedures are not common in this command.
5. The command recognizes individual safety achievement through rewards and incentives.
6. Personnel are comfortable approaching supervisors about personal problems/illness.
7. Safety NCO, QAR, and CDI, are sought after billets.
8. Unprofessional behavior is not tolerated in the command.

COMPONENT 3: QUALITY ASSURANCE

1. The command has a reputation for quality maintenance and has set standards to maintain quality control.
2. QA and Safety are well respected, and are seen as essential to mission accomplishment.
3. QARs/CDIs sign-off after required actions are complete and are not pressured by supervisors to sign-off.
4. Maintenance on detachments is the same quality as that at home station.
5. Required publications/tools/equipment are available, current/serviceable, and used.
6. QARs are helpful, and QA is not “feared” in my unit.

COMPONENT 4: RISK MANAGEMENT

1. Multiple job assignments and collateral duties adversely affect maintenance.
2. Safety is part of maintenance planning, and additional training/support is provided as needed.
3. Supervisors recognize unsafe conditions and manage hazards associated with maintenance and the flight line.
4. I am provided adequate resources, time, personnel to accomplish my job.
5. Personnel turnover does not negatively impact the command's ability to operate safely.
6. Supervisors are more concerned with safe maintenance than the flight schedule, and do not permit cutting corners.
7. Day/Night Check have equal workloads, and staffing is sufficient on each shift.
8. Supervisors shield personnel from outside pressures and are aware of individual workload.
9. Based upon my command's current assets/manning it is not over-committed.

COMPONENT 5: COMMAND AND CONTROL

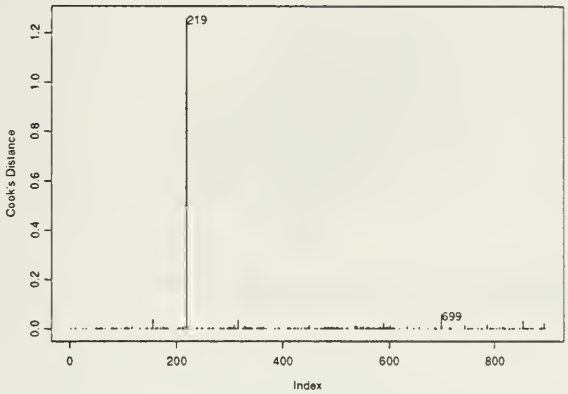
1. My command temporarily restricts maintainers who are having problems.
2. Safety decisions are made at the proper levels, work center supervisors decisions are respected.
3. Supervisors communicate command safety goals and are actively engaged in the safety program.
4. Supervisors set the example for following to maintenance standards and ensure compliance.
5. In my command safety is a key part of all maintenance operations and all are responsible/accountable for safety.
6. Safety education and training are comprehensive and effective.
7. All maintenance evolutions are properly briefed, supervised, and staffed by qualified personnel.
8. Maintenance control is effective in managing all maintenance activities.

COMPONENT 6: COMMUNICATION / FUNCTIONAL RELATIONSHIPS

1. Good communication exists up/down the chain of command.
2. I get all the information I need to do my job safely.
3. Work center supervisors coordinate their actions.
4. My command has effective pass-down between shifts.
5. Maintenance Control troubleshoots/resolves gripes before flight.
6. Maintainers are briefed on potential hazards associated with maintenance activities.

APPENDIX C. INFLUENCE PLOTS FOR AUGMENTED MOSE COMPONENTS

PA



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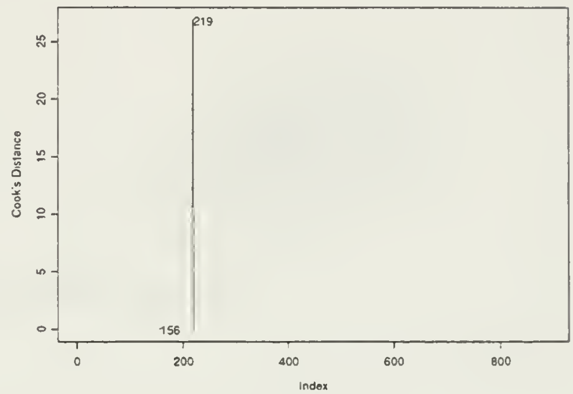

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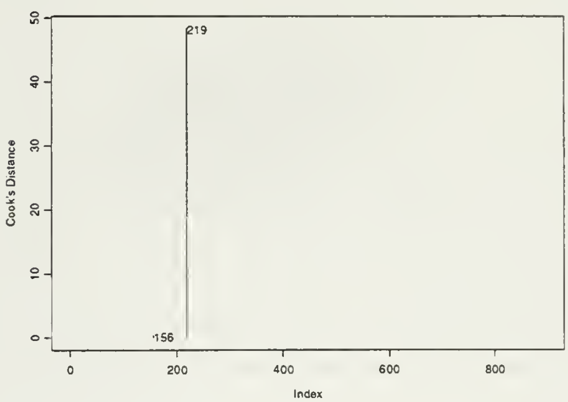

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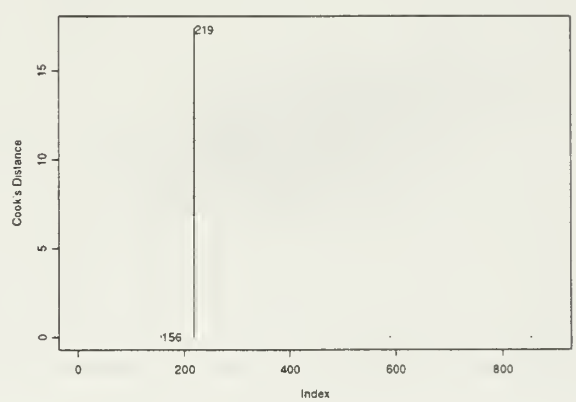

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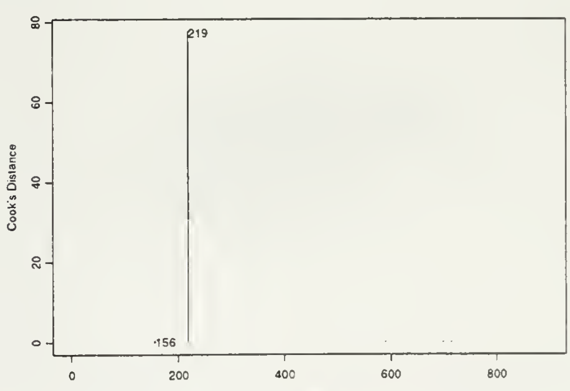

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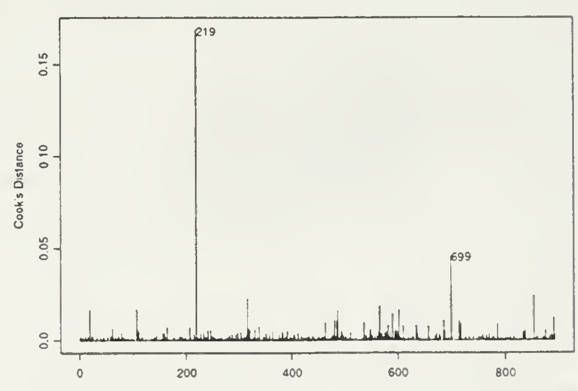

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APPENDIX D. SIMPLE MODELS: SCATTERPLOTS WITH SUPERIMPOSED REGRESSION LINE

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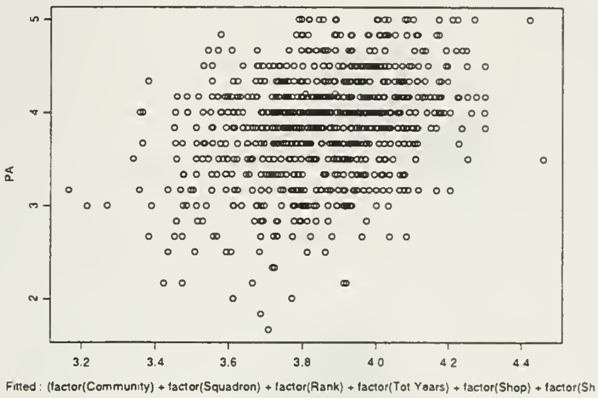

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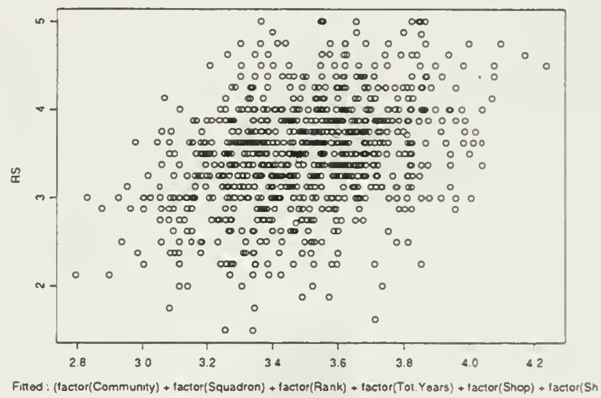

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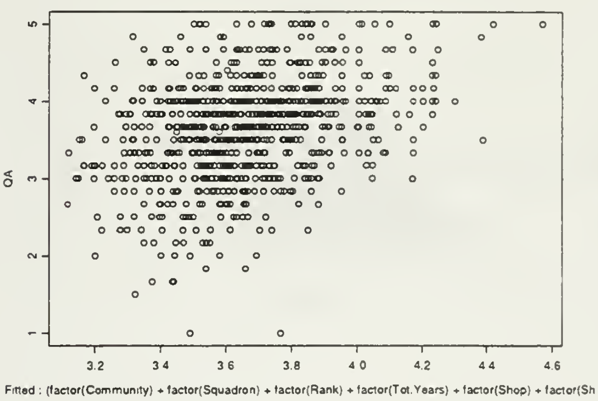

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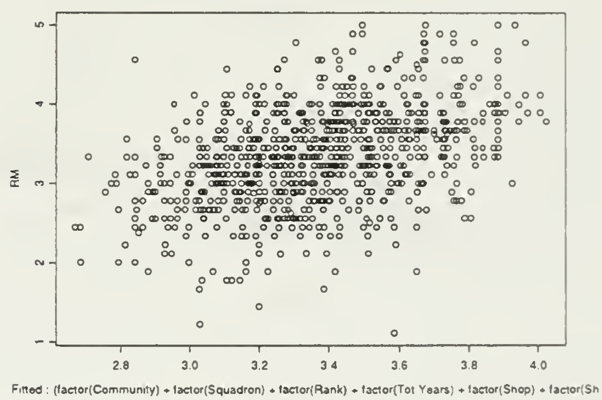

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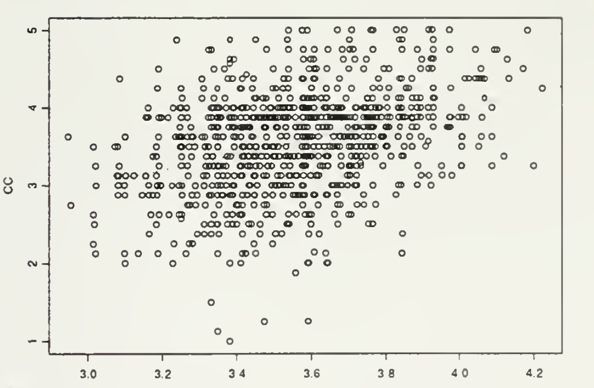

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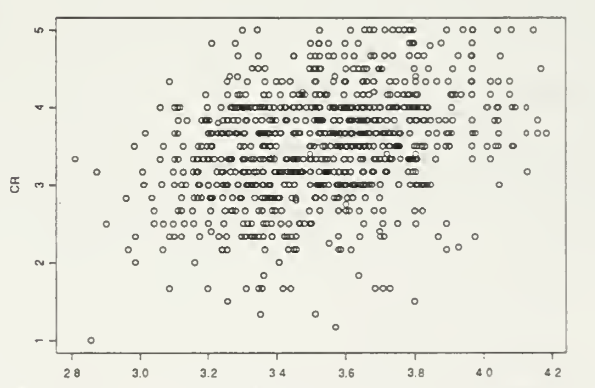

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APPENDIX E. SIMPLE MODELS: HISTOGRAMS OF RESIDUALS

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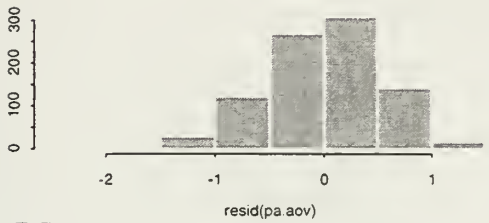

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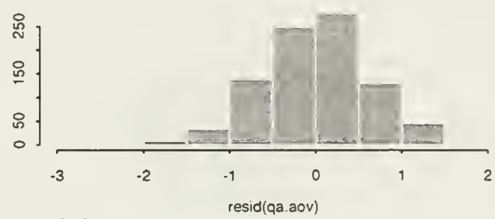

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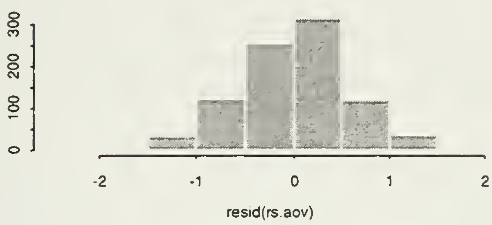

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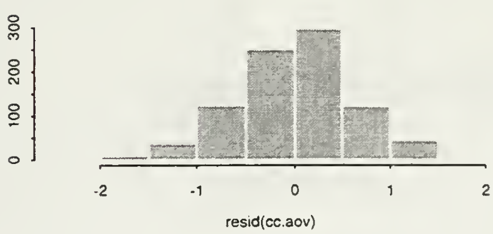

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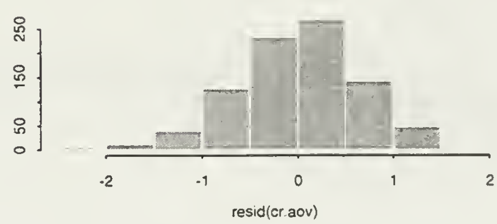

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APPENDIX F. SIMPLE MODELS: RESIDUALS VERSUS FITTED VALUESWITH LOWESS SMOOTHING

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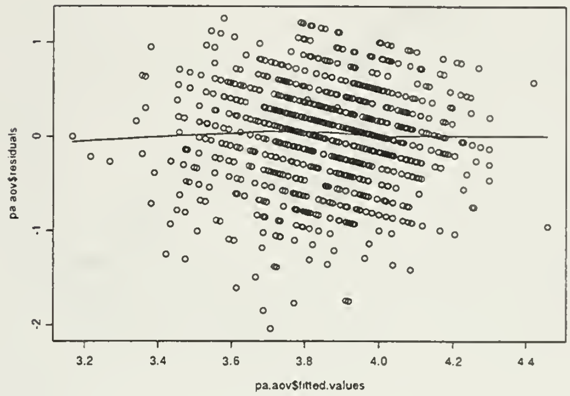

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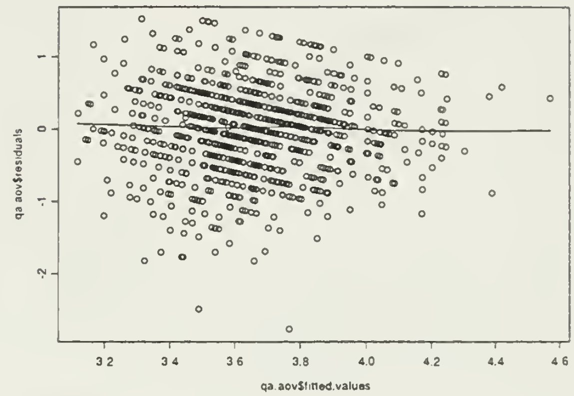

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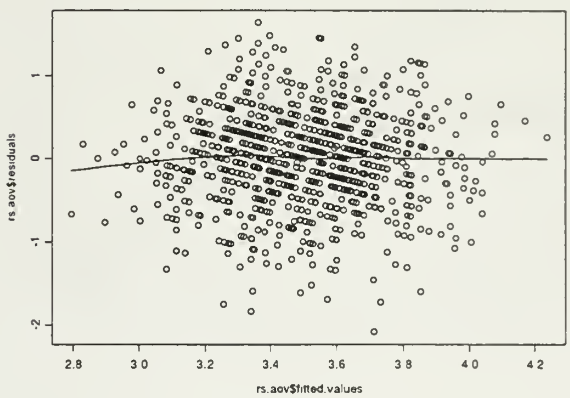

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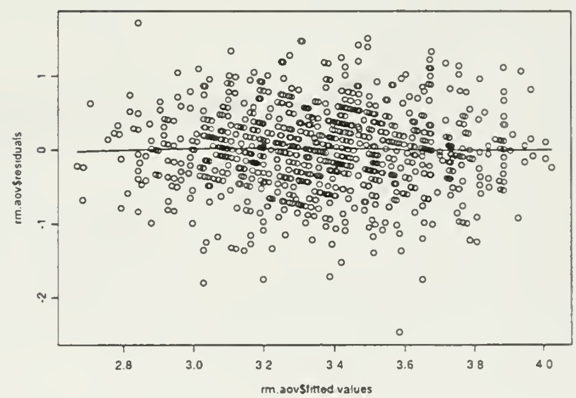

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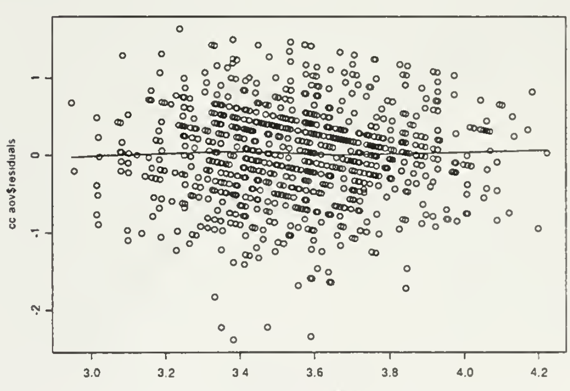

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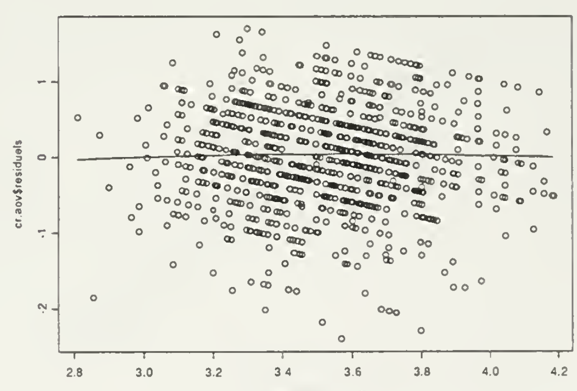

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APPENDIX G. SIMPLE MODELS: QQ-PLOTS

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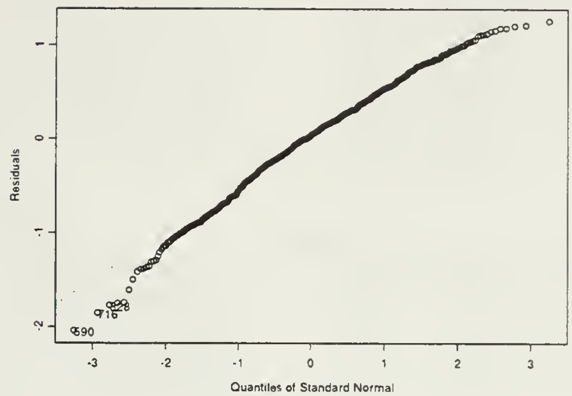

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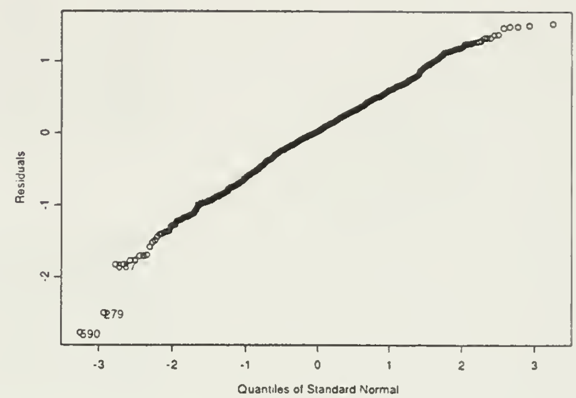

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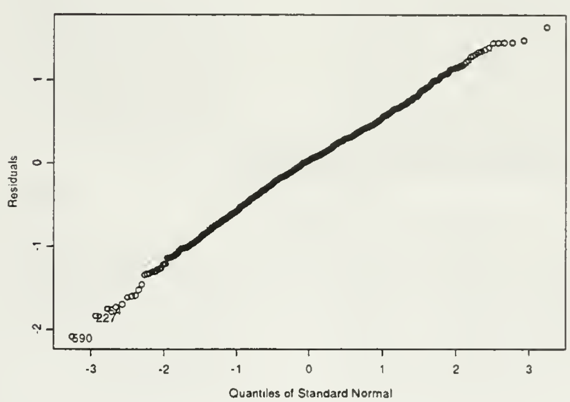

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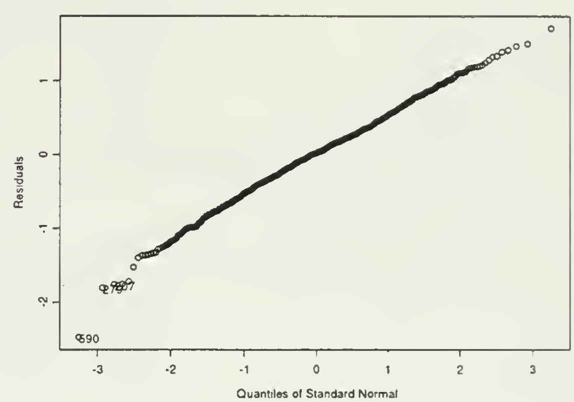

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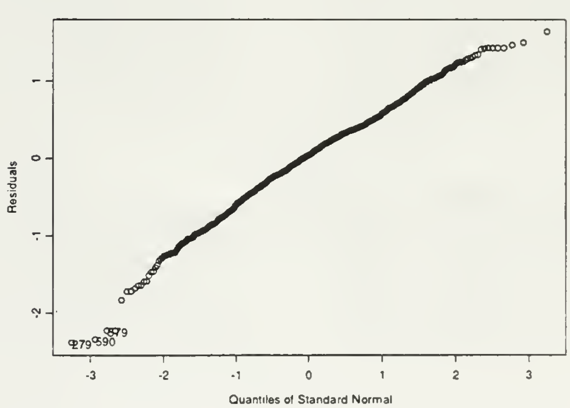

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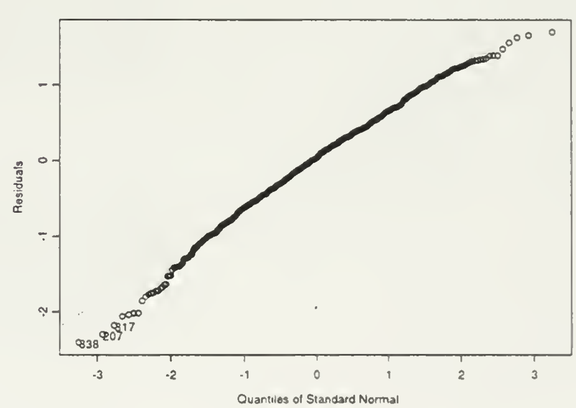

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APPENDIX H. SIMPLE MODELS: ANALYSIS OF VARIANCE

PA

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	8.3925	1.198929	3.922101	0.0003198
factor(Squadron)	13	8.0763	0.621257	2.032343	0.0160499
factor(Rank)	6	6.0359	1.005978	3.290893	0.0033082
factor(Tot.Years)	6	3.4403	0.573388	1.875746	0.0821892
factor(Shop)	9	3.2828	0.364753	1.193231	0.2957039
factor(Shift)	1	2.7153	2.715335	8.882780	0.0029608
Residuals	850	259.8325	0.305685		

QA

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	8.3910	1.198710	2.994574	0.0041284
factor(Squadron)	13	14.3600	1.104618	2.759519	0.0007443
factor(Rank)	6	12.2469	2.041156	5.099143	0.0000372
factor(Tot.Years)	6	7.6351	1.272514	3.178950	0.0043234
factor(Shop)	9	3.9649	0.440543	1.100548	0.3596172
factor(Shift)	1	0.6428	0.642779	1.605767	0.2054349
Residuals	850	340.2498	0.400294		

RS

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	3.7699	0.538562	1.549360	0.1471909
factor(Squadron)	13	12.7604	0.981569	2.823824	0.0005582
factor(Rank)	6	17.8319	2.971978	8.549925	0.0000000
factor(Tot.Years)	6	7.6649	1.277490	3.675142	0.0013048
factor(Shop)	9	5.4436	0.604846	1.740050	0.0761483
factor(Shift)	1	1.7291	1.729082	4.974302	0.0259869
Residuals	850	295.4624	0.347603		

RM

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	15.9912	2.284458	7.056521	0.0000000
factor(Squadron)	13	11.8830	0.914080	2.823525	0.0005590
factor(Rank)	6	19.2158	3.202630	9.892685	0.0000000
factor(Tot.Years)	6	10.5421	1.757022	5.427311	0.0000161
factor(Shop)	9	4.8880	0.543110	1.677627	0.0901813
factor(Shift)	1	0.7475	0.747503	2.308980	0.1290003
Residuals	850	275.1766	0.323737		

CC

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factor(Community)	7	9.8503	1.407189	3.490669	0.0010676
factor(Squadron)	13	12.2826	0.944816	2.343707	0.0045142
factor(Rank)	6	15.1026	2.517097	6.243904	0.0000020
factor(Tot.Years)	6	6.7176	1.119607	2.777295	0.0111256
factor(Shop)	9	3.5477	0.394188	0.977822	0.4567736
factor(Shift)	1	2.8159	2.815870	6.985039	0.0083707
Residuals	850	342.6594	0.403129		

CR

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	12.4423	1.777478	3.792880	0.0004599
factor(Squadron)	13	11.0908	0.853140	1.820477	0.0361248
factor(Rank)	6	18.6478	3.107964	6.631942	0.0000007
factor(Tot.Years)	6	9.4231	1.570522	3.351265	0.0028616
factor(Shop)	9	3.7036	0.411516	0.878115	0.5443707
factor(Shift)	1	0.7389	0.738887	1.576677	0.2095850
Residuals	850	398.3402	0.468636		

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APPENDIX I. TWO FACTOR INTERACTION MODELS: SCATTERPLOTS WITH SUPERIMPOSED REGRESSION LINE

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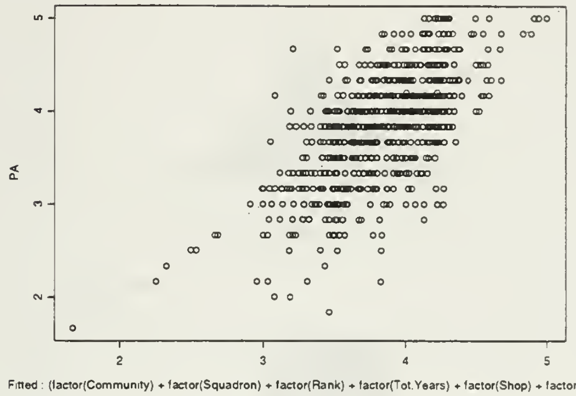

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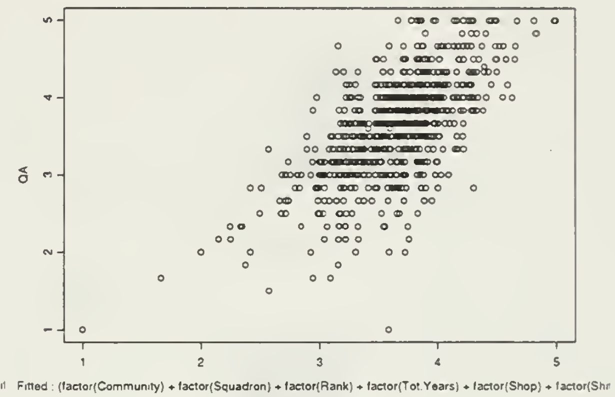

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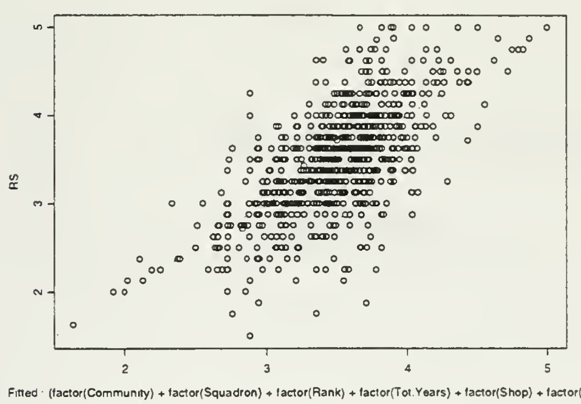

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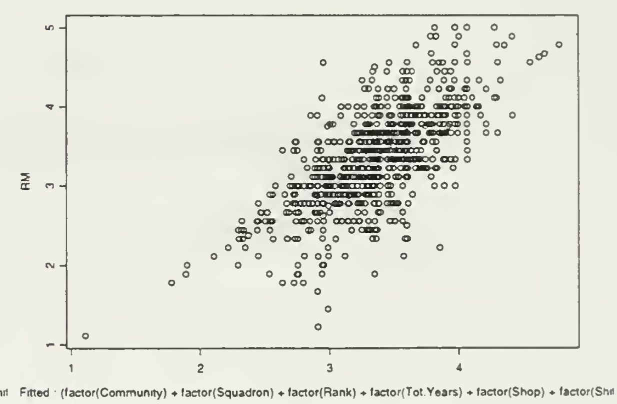

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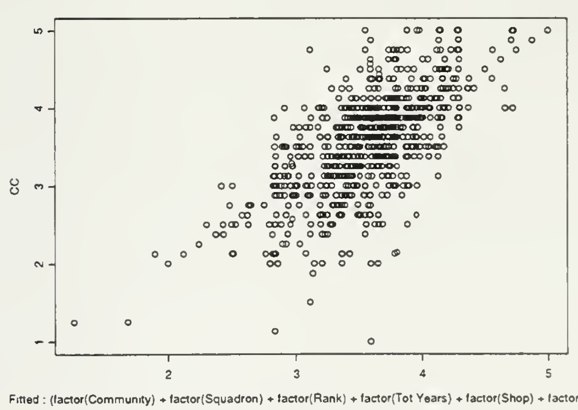

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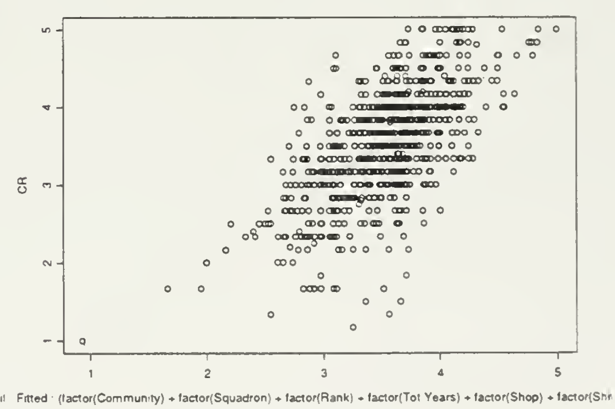

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APPENDIX J. TWO FACTOR INTERACTION MODELS: HISTOGRAMS OF RESIDUALS

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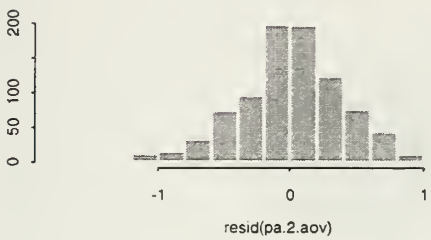

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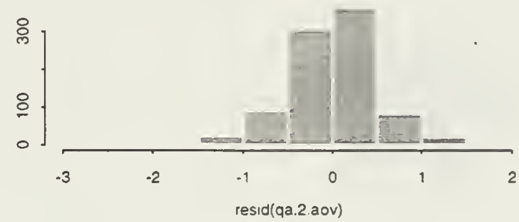

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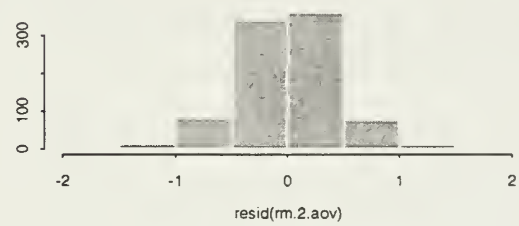

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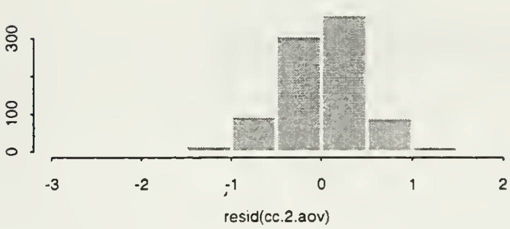

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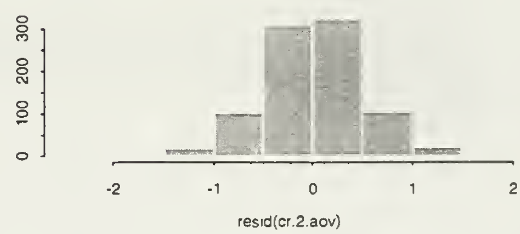

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APPENDIX K. TWO FACTOR INTERACTION MODELS: RESIDUALS VERSUS FITTED VALUES WITH LOESS SMOOTHING

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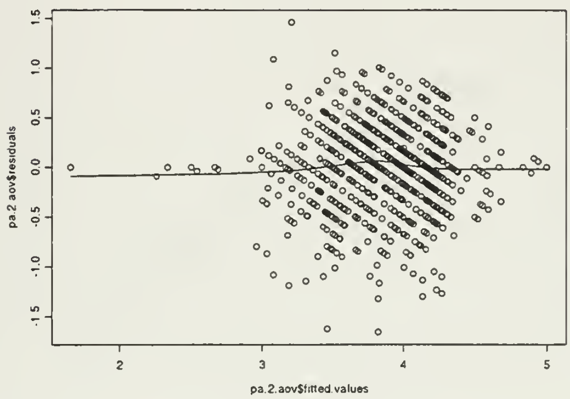

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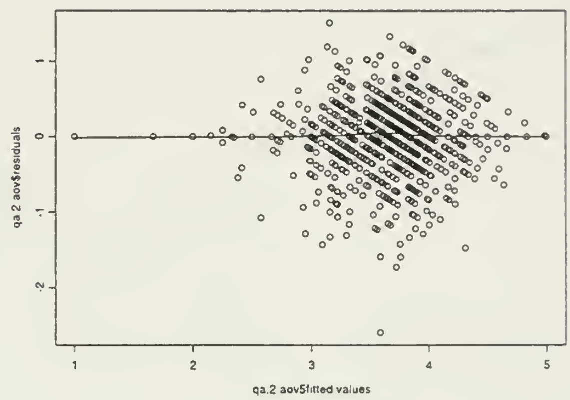

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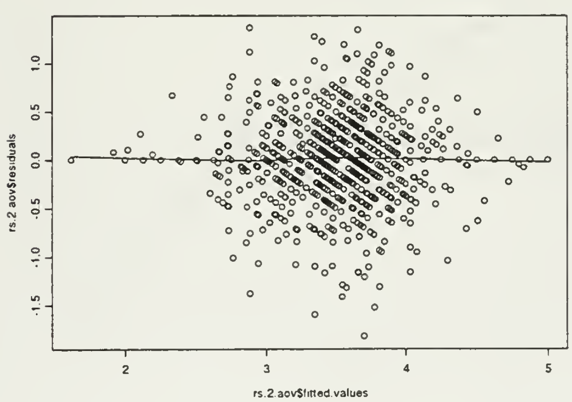

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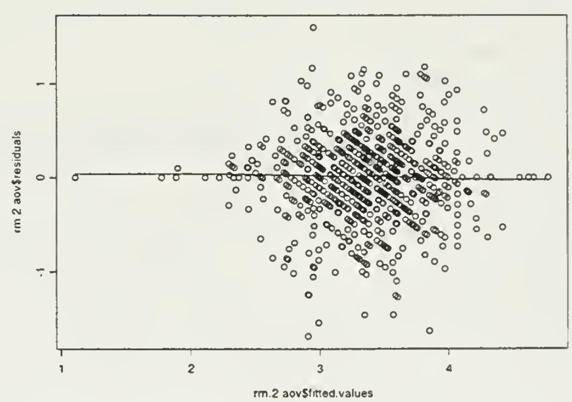

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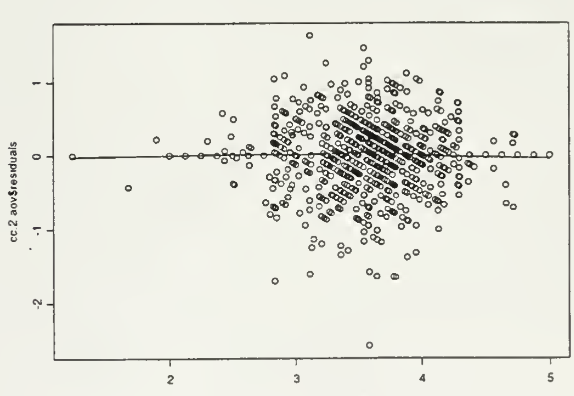

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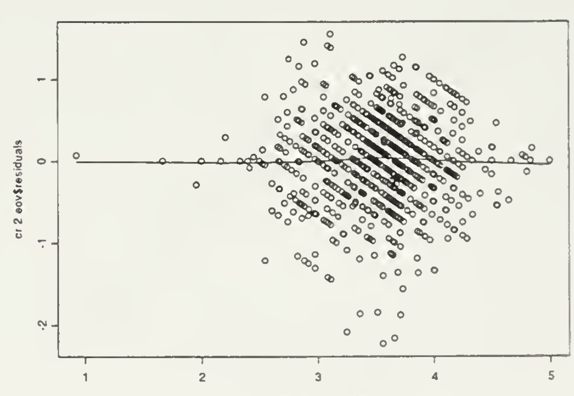

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APPENDIX L. TWO FACTOR INTERACTION MODELS: QQ-PLOTS

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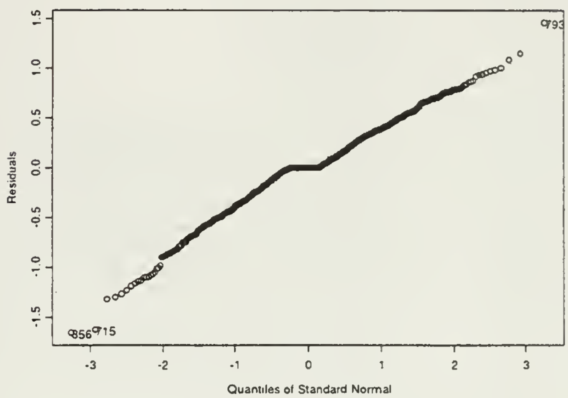

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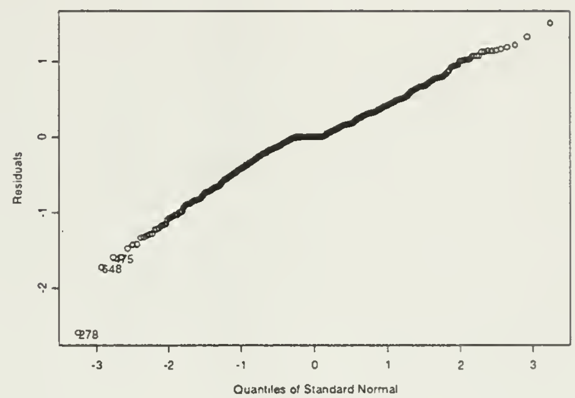

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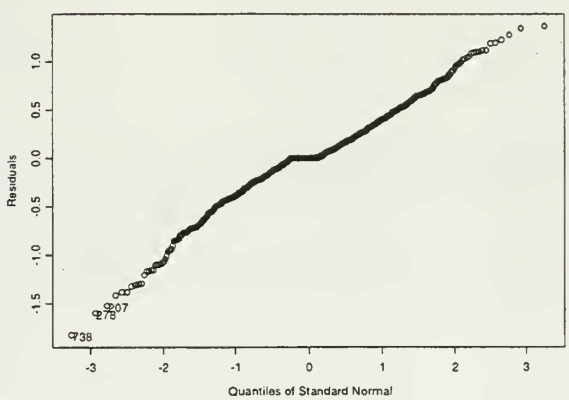

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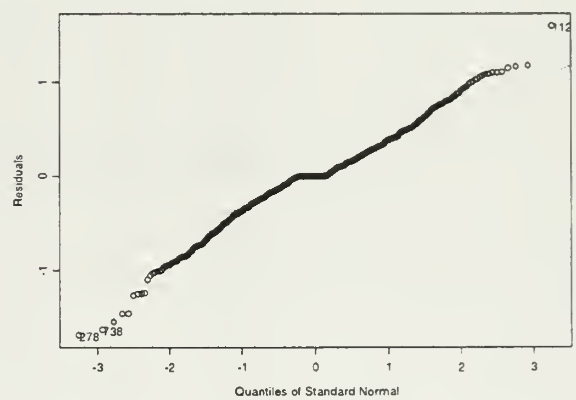

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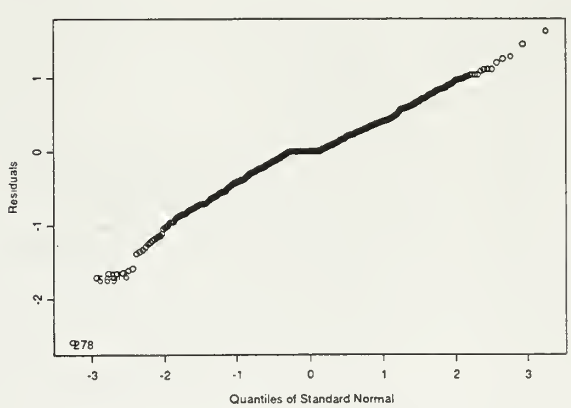

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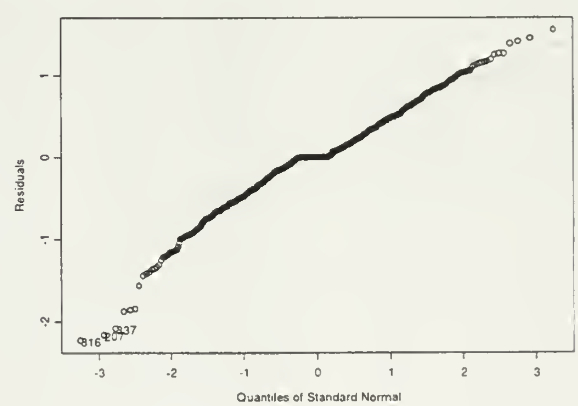

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APPENDIX M. TWO FACTOR INTERACTION MODELS: ANALYSIS OF VARIANCE

PA

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	8.3925	1.198929	4.356653	0.0001027
factor(Squadron)	13	8.0763	0.621257	2.257518	0.0068172
factor(Rank)	6	6.0359	1.005978	3.655510	0.0014394
factor(Tot.Years)	6	3.4403	0.573388	2.083571	0.0534953
factor(Shop)	9	3.2828	0.364753	1.325436	0.2203764
factor(Shift)	1	2.7153	2.715335	9.866954	0.0017732
factor(Community):factor(Rank)	27	8.5470	0.316557	1.150301	0.2755360
factor(Community):factor(Tot.Years)	32	5.5049	0.172029	0.625117	0.9480617
factor(Community):factor(Shop)	46	16.8120	0.365478	1.328069	0.0778513
factor(Community):factor(Shift)	5	4.8802	0.976038	3.546715	0.0036412
factor(Squadron):factor(Rank)	27	7.1875	0.266205	0.967334	0.5134968
factor(Squadron):factor(Tot.Years)	37	16.5409	0.447050	1.624486	0.0126771
factor(Squadron):factor(Shop)	56	23.4663	0.419042	1.522709	0.0108588
factor(Squadron):factor(Shift)	6	3.7496	0.624928	2.270855	0.0356434
factor(Rank):factor(Tot.Years)	8	3.4152	0.426899	1.551259	0.1367135
factor(Rank):factor(Shop)	15	5.1111	0.340743	1.238189	0.2382294
factor(Rank):factor(Shift)	2	0.4713	0.235625	0.856213	0.4253331
factor(Tot.Years):factor(Shop)	29	8.8454	0.305014	1.108357	0.3199687
factor(Tot.Years):factor(Shift)	3	0.7165	0.238846	0.867915	0.4574968
factor(Shop):factor(Shift)	7	3.2273	0.461047	1.675347	0.1124277
Residuals	550	151.3572	0.275195		

QA

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	8.3910	1.198710	3.292186	0.0019394
factor(Squadron)	13	14.3600	1.104618	3.033770	0.0002431
factor(Rank)	6	12.2469	2.041156	5.605916	0.0000116
factor(Tot.Years)	6	7.6351	1.272514	3.494886	0.0021165
factor(Shop)	9	3.9649	0.440543	1.209925	0.2860380
factor(Shift)	1	0.6428	0.642779	1.765354	0.1845090
factor(Community):factor(Rank)	27	10.0763	0.373196	1.024962	0.4313503
factor(Community):factor(Tot.Years)	32	10.2932	0.321663	0.883428	0.6538426
factor(Community):factor(Shop)	46	23.9700	0.521087	1.431136	0.0362521
factor(Community):factor(Shift)	5	11.2388	2.247751	6.173318	0.0000140
factor(Squadron):factor(Rank)	27	17.7225	0.656389	1.802734	0.0083195
factor(Squadron):factor(Tot.Years)	37	15.4891	0.418624	1.149727	0.2540719
factor(Squadron):factor(Shop)	56	22.7429	0.406123	1.115393	0.2703154
factor(Squadron):factor(Shift)	6	3.5604	0.593400	1.629737	0.1365990
factor(Rank):factor(Tot.Years)	8	5.2739	0.659237	1.810557	0.0725066
factor(Rank):factor(Shop)	15	7.4882	0.499213	1.371060	0.1561216
factor(Rank):factor(Shift)	2	1.7580	0.879015	2.414162	0.0903895
factor(Tot.Years):factor(Shop)	29	7.0553	0.243286	0.668170	0.9075797
factor(Tot.Years):factor(Shift)	3	0.8364	0.278789	0.765679	0.5136070
factor(Shop):factor(Shift)	7	2.4857	0.355105	0.975276	0.4483208
Residuals	550	200.2591	0.364107		

RS

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	3.7699	0.538562	1.734800	0.0984123
factor(Squadron)	13	12.7604	0.981569	3.161802	0.0001365
factor(Rank)	6	17.8319	2.971978	9.573249	0.0000000
factor(Tot.Years)	6	7.6649	1.277490	4.115013	0.0004719
factor(Shop)	9	5.4436	0.604846	1.948314	0.0432207
factor(Shift)	1	1.7291	1.729082	5.569667	0.0186225
factor(Community):factor(Rank)	27	8.6010	0.318554	1.026117	0.4297560
factor(Community):factor(Tot.Years)	32	5.9900	0.187188	0.602964	0.9597519
factor(Community):factor(Shop)	46	19.4596	0.423035	1.362667	0.0607806
factor(Community):factor(Shift)	5	6.8711	1.374220	4.426596	0.0005820
factor(Squadron):factor(Rank)	27	12.1684	0.450680	1.451719	0.0672413
factor(Squadron):factor(Tot.Years)	37	14.7707	0.399208	1.285918	0.1242051
factor(Squadron):factor(Shop)	56	26.1193	0.466416	1.502405	0.0132179
factor(Squadron):factor(Shift)	6	4.7507	0.791781	2.550461	0.0191331
factor(Rank):factor(Tot.Years)	8	3.5565	0.444564	1.432017	0.1800429
factor(Rank):factor(Shop)	15	4.1334	0.275561	0.887628	0.5783215
factor(Rank):factor(Shift)	2	1.6918	0.845879	2.724720	0.0664497
factor(Tot.Years):factor(Shop)	29	10.6388	0.366855	1.181702	0.2373524
factor(Tot.Years):factor(Shift)	3	2.3787	0.792884	2.554013	0.0546501
factor(Shop):factor(Shift)	7	3.5872	0.512457	1.650712	0.1187383
Residuals	550	170.7454	0.310446		

RM

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	15.9912	2.284458	7.74590	0.0000000
factor(Squadron)	13	11.8830	0.914080	3.09937	0.0001810
factor(Rank)	6	19.2158	3.202630	10.85914	0.0000000
factor(Tot.Years)	6	10.5421	1.757022	5.95752	0.0000048
factor(Shop)	9	4.8880	0.543110	1.84152	0.0583837
factor(Shift)	1	0.7475	0.747503	2.53455	0.1119530
factor(Community):factor(Rank)	27	6.1172	0.226562	0.76820	0.7946819
factor(Community):factor(Tot.Years)	32	7.0593	0.220602	0.74799	0.8421223
factor(Community):factor(Shop)	46	15.9480	0.346696	1.17554	0.2054702
factor(Community):factor(Shift)	5	12.6939	2.538785	8.60824	0.0000001
factor(Squadron):factor(Rank)	27	10.8087	0.400322	1.35737	0.1093488
factor(Squadron):factor(Tot.Years)	37	12.4608	0.336778	1.14191	0.2636165
factor(Squadron):factor(Shop)	56	20.8355	0.372062	1.26155	0.1036550
factor(Squadron):factor(Shift)	6	5.6544	0.942395	3.19537	0.0043116
factor(Rank):factor(Tot.Years)	8	2.4103	0.301291	1.02158	0.4183172
factor(Rank):factor(Shop)	15	4.4618	0.297452	1.00857	0.4442584
factor(Rank):factor(Shift)	2	2.6308	1.315404	4.46013	0.0119820
factor(Tot.Years):factor(Shop)	29	8.4000	0.289655	0.98213	0.4942530
factor(Tot.Years):factor(Shift)	3	1.2055	0.401827	1.36247	0.2533738
factor(Shop):factor(Shift)	7	2.2818	0.325976	1.10528	0.3581240
Residuals	550	162.2087	0.294925		

CR

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	12.4423	1.777478	4.177394	0.0001697
factor(Squadron)	13	11.0908	0.853140	2.005033	0.0185347
factor(Rank)	6	18.6478	3.107964	7.304274	0.0000002
factor(Tot.Years)	6	9.4231	1.570522	3.691009	0.0013214
factor(Shop)	9	3.7036	0.411516	0.967136	0.4662855
factor(Shift)	1	0.7389	0.738887	1.736518	0.1881293
factor(Community):factor(Rank)	27	10.0529	0.372329	0.875041	0.6494108
factor(Community):factor(Tot.Years)	32	10.0165	0.313016	0.735645	0.8559696
factor(Community):factor(Shop)	46	30.3247	0.659233	1.549317	0.0137593
factor(Community):factor(Shift)	5	8.1375	1.627495	3.824905	0.0020492
factor(Squadron):factor(Rank)	27	14.7948	0.547957	1.287797	0.1526769
factor(Squadron):factor(Tot.Years)	37	19.5299	0.527835	1.240507	0.1600404
factor(Squadron):factor(Shop)	56	36.1636	0.645778	1.517696	0.0114023
factor(Squadron):factor(Shift)	6	3.4718	0.578626	1.359876	0.2288249
factor(Rank):factor(Tot.Years)	8	4.5586	0.569829	1.339200	0.2212122
factor(Rank):factor(Shop)	15	6.5391	0.435941	1.024540	0.4275257
factor(Rank):factor(Shift)	2	1.2651	0.632559	1.486627	0.2270415
factor(Tot.Years):factor(Shop)	29	14.0630	0.484930	1.139672	0.2827731
factor(Tot.Years):factor(Shift)	3	2.2102	0.736717	1.731418	0.1594515
factor(Shop):factor(Shift)	7	3.1879	0.455411	1.070298	0.3811256
Residuals	550	234.0246	0.425499		

CC

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
factor(Community)	7	9.8503	1.407189	3.913888	0.0003535
factor(Squadron)	13	12.2826	0.944816	2.627865	0.0014467
factor(Rank)	6	15.1026	2.517097	7.000932	0.0000003
factor(Tot.Years)	6	6.7176	1.119607	3.114022	0.0052210
factor(Shop)	9	3.5477	0.394188	1.096376	0.3634308
factor(Shift)	1	2.8159	2.815870	7.831926	0.0053132
factor(Community):factor(Rank)	27	8.8346	0.327206	0.910074	0.5979349
factor(Community):factor(Tot.Years)	32	8.7848	0.274526	0.763554	0.8237228
factor(Community):factor(Shop)	46	20.7928	0.452016	1.257217	0.1253496
factor(Community):factor(Shift)	5	10.1673	2.033454	5.655750	0.0000426
factor(Squadron):factor(Rank)	27	11.6354	0.430941	1.198599	0.2264270
factor(Squadron):factor(Tot.Years)	37	17.7331	0.479274	1.333030	0.0940917
factor(Squadron):factor(Shop)	56	27.8577	0.497460	1.383610	0.0390184
factor(Squadron):factor(Shift)	6	5.1754	0.862573	2.399120	0.0268520
factor(Rank):factor(Tot.Years)	8	5.4297	0.678707	1.887723	0.0595526
factor(Rank):factor(Shop)	15	6.9073	0.460485	1.280770	0.2089887
factor(Rank):factor(Shift)	2	1.7807	0.890356	2.476393	0.0849826
factor(Tot.Years):factor(Shop)	29	14.6705	0.505881	1.407033	0.0788824
factor(Tot.Years):factor(Shift)	3	2.0737	0.691223	1.922534	0.1248178
factor(Shop):factor(Shift)	7	3.0709	0.438695	1.220166	0.2894603
Residuals	550	197.7456	0.359537		

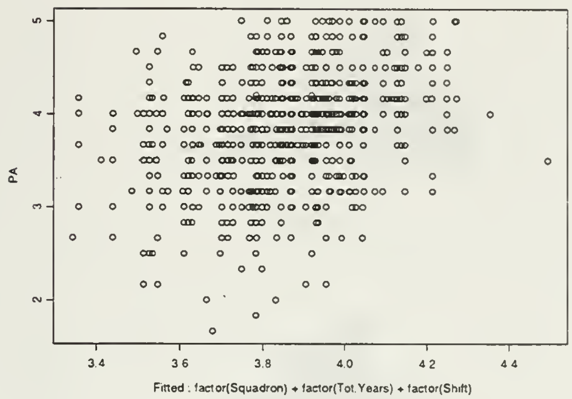
APPENDIX N. REDUCED SIMPLE MODELS

```
Model:
PA ~ factor(Squadron) + factor(Tot.Years) + factor(Shift)

scale:  0.3056853

                  Df Sum of Sq      RSS       Cp
           <none>              265.0655 281.5725
 factor(Squadron) 19  19.09854 284.1640 289.0550
factor(Tot.Years)  6   6.98011 272.0456 284.8844
    factor(Shift)  1   2.98713 268.0526 283.9482

Terms:
                factor(Squadron) factor(Tot.Years) factor(Shift) Residuals
 Sum of Squares          16.4369            7.2861        2.9871  265.0655
Deg. of Freedom               19                 6             1       866

Residual standard error: 0.5532452
Estimated effects may be unbalanced


QA ~ factor(Squadron) + factor(Tot.Years) + factor(Shift)

scale:  0.4002939

                  Df Sum of Sq      RSS       Cp
           <none>              348.6818 370.2977
 factor(Squadron) 19  23.06513 371.7469 378.1516
factor(Tot.Years)  6  15.45358 364.1354 380.9477
    factor(Shift)  1   0.90043 349.5822 370.3975

Terms:
                factor(Squadron) factor(Tot.Years) factor(Shift) Residuals
 Sum of Squares          22.4130           15.4952        0.9004  348.6818
Deg. of Freedom               19                 6             1       866

Residual standard error: 0.6345352
Estimated effects may be unbalanced

Model:
RS ~ factor(Squadron) + factor(Rank) + factor(Tot.Years) + factor(Shift)

scale:  0.3476029

                  Df Sum of Sq      RSS       Cp
           <none>              301.9366 324.8784
 factor(Squadron) 19  16.56125 318.4979 328.2308
     factor(Rank)  6   5.50006 307.4367 326.2072
factor(Tot.Years)  6   7.70716 309.6438 328.4143
    factor(Shift)  1   1.04953 302.9861 325.2327

Terms:
                factor(Squadron) factor(Rank) factor(Tot.Years) factor(Shift) Residuals
 Sum of Squares          16.0094      18.0278            7.6388        1.0495  301.9366
Deg. of Freedom               19            6                 6             1       860

Residual standard error: 0.5925277
Estimated effects may be unbalanced

Model:
RM ~ factor(Squadron) + factor(Rank) + factor(Tot.Years)

scale:  0.3237372

                  Df Sum of Sq      RSS       Cp
           <none>              280.8129 301.5321
```

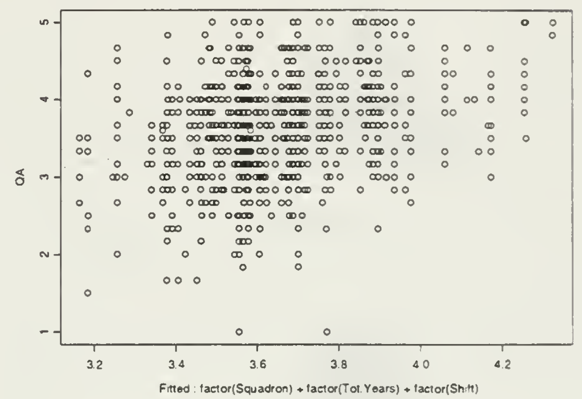
```
 factor(Squadron) 19  23.32159 304.1345 312.5517
     factor(Rank)  6   5.07801 285.8909 302.7253
factor(Tot.Years)  6  10.54164 291.3546 308.1889

Terms:
                factor(Squadron) factor(Rank) factor(Tot.Years) Residuals
 Sum of Squares          27.8628      19.2269           10.5416  280.8129
Deg. of Freedom               19            6                 6       861

Residual standard error: 0.5710932
Estimated effects may be unbalanced

Model:
CC ~ factor(Squadron) + factor(Tot.Years) + factor(Shift)

scale:  0.4031287

                  Df Sum of Sq      RSS       Cp
           <none>              350.8909 372.6598
 factor(Squadron) 19  22.16263 373.0535 379.5036
factor(Tot.Years)  6  17.43463 368.3255 385.2569
    factor(Shift)  1   2.80445 353.6953 374.6580

Terms:
                factor(Squadron) factor(Tot.Years) factor(Shift) Residuals
 Sum of Squares          22.0953           17.1855        2.8045  350.8909
Deg. of Freedom               19                 6             1       866

Residual standard error: 0.636542
Estimated effects may be unbalanced

Model:
CR ~ factor(Community) + factor(Tot.Years) + factor(Shift)

scale:  0.4686355

                  Df Sum of Sq      RSS       Cp
           <none>              418.7697 432.8288
factor(Community)  7  10.24208 429.0118 436.5100
factor(Tot.Years)  6  21.33850 440.1082 448.5437
    factor(Shift)  1   1.89642 420.6661 433.7879

Terms:
                factor(Community) factor(Tot.Years) factor(Shift) Residuals
 Sum of Squares           12.4423           21.2783        1.8964  418.7697
Deg. of Freedom                 7                 6             1       878

Residual standard error: 0.690622
Estimated effects may be unbalanced
```

APPENDIX O. REDUCED SIMPLE MODELS: SCATTERPLOTS WITH SUPERIMPOSED REGRESSION LINE

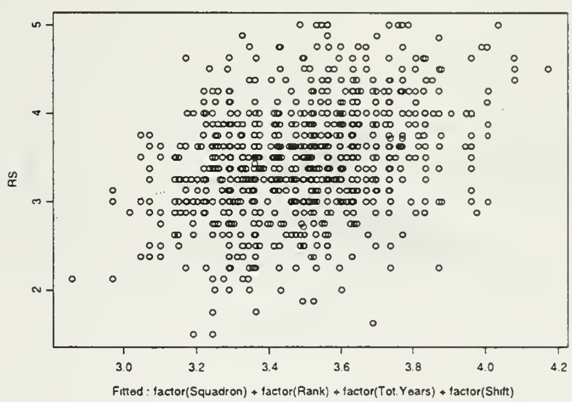
PA



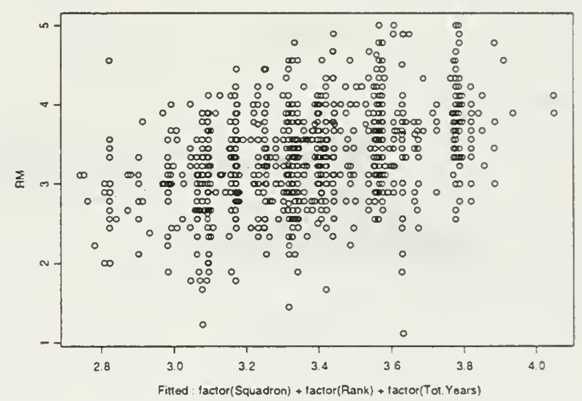
QA



RS



RM



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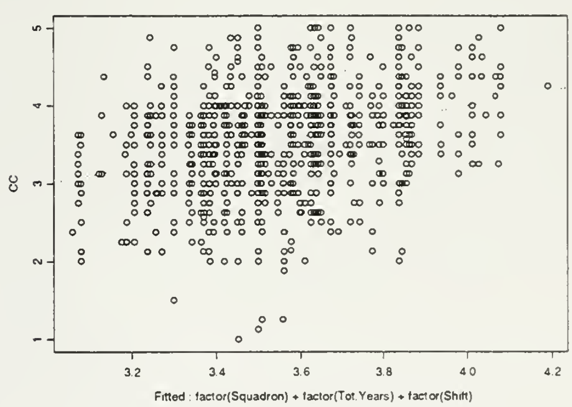

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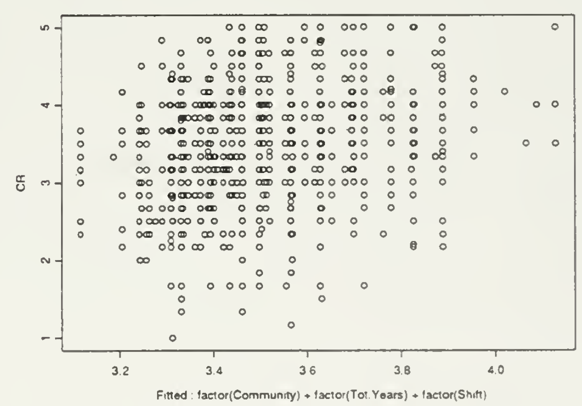

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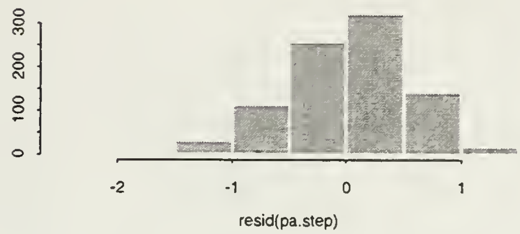
APPENDIX P. REDUCED SIMPLE MODELS: HISTOGRAMS OF RESIDUALS

PA



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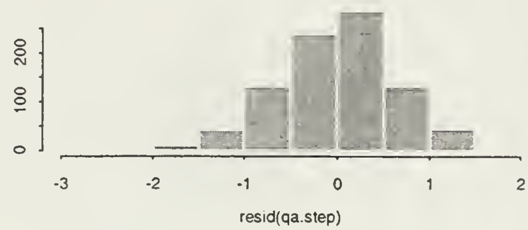

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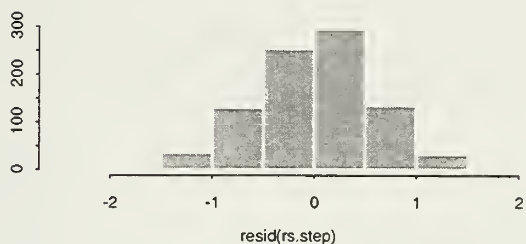

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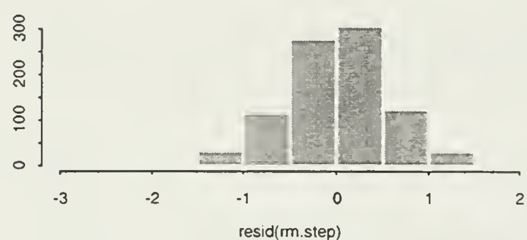

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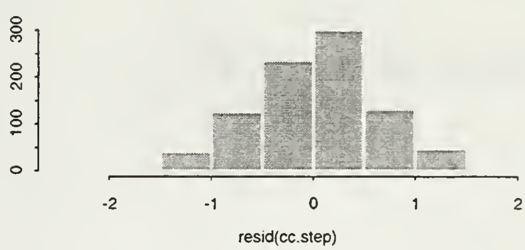

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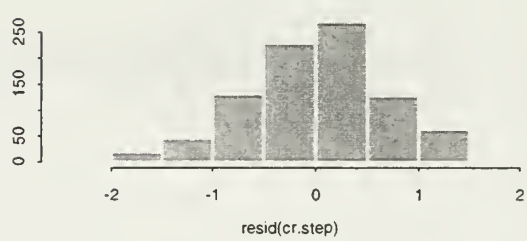

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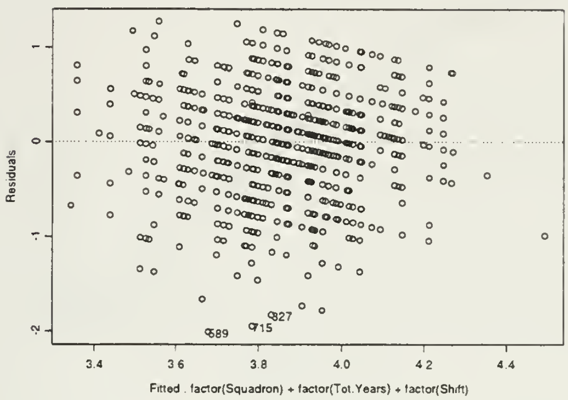
APPENDIX Q. REDUCED SIMPLE MODELS: RESIDUALS VERSUS FITTED VALUES

PA



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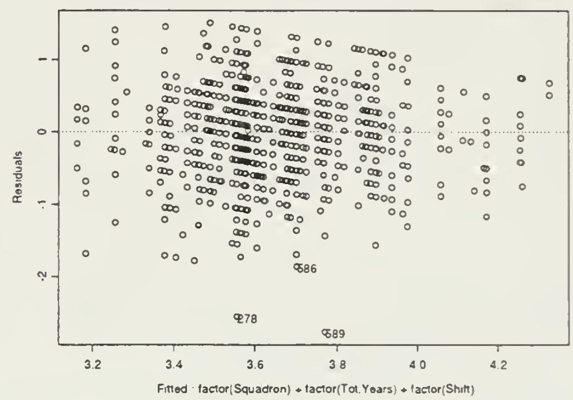

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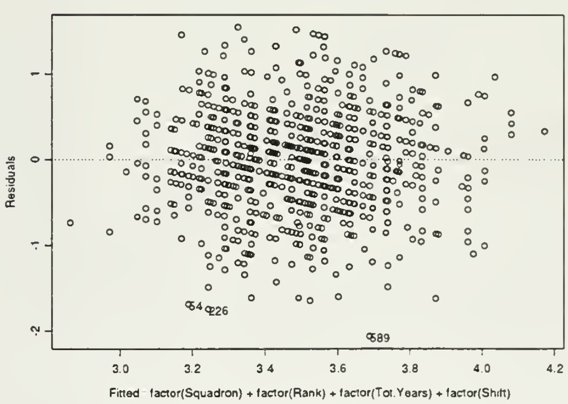

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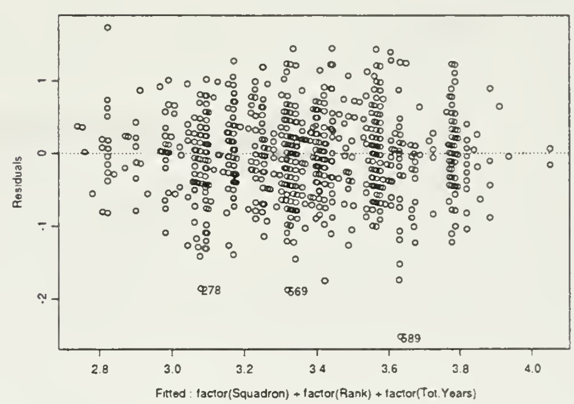

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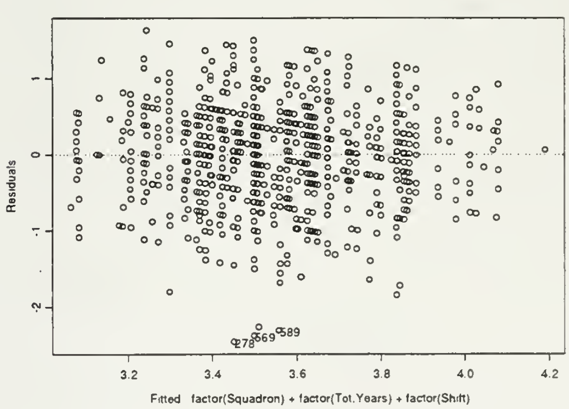

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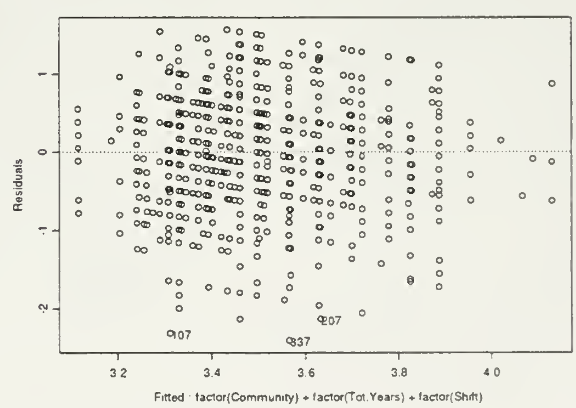

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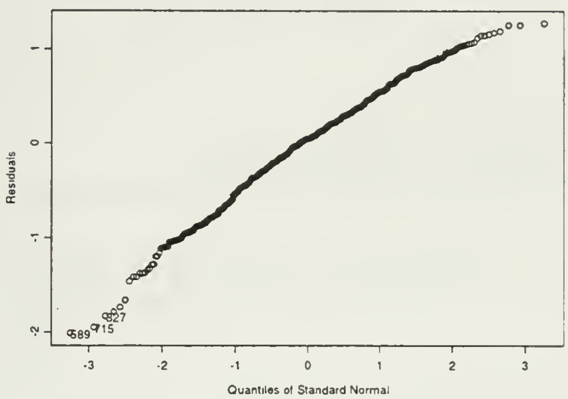
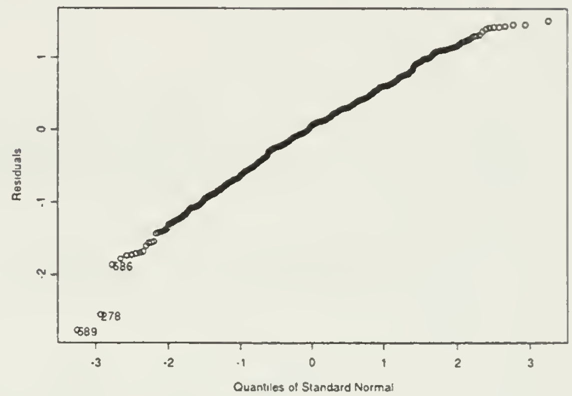
APPENDIX R. REDUCED SIMPLE MODELS: QQ-PLOTS

PA



QA



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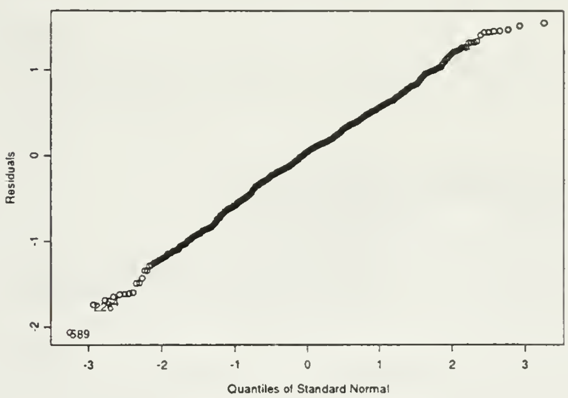

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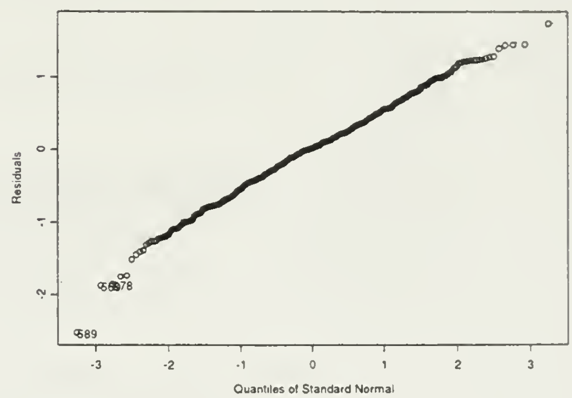

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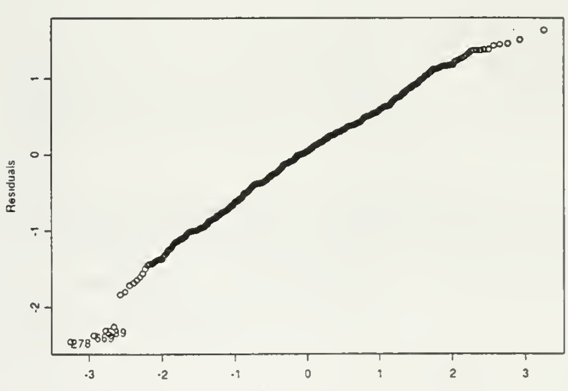

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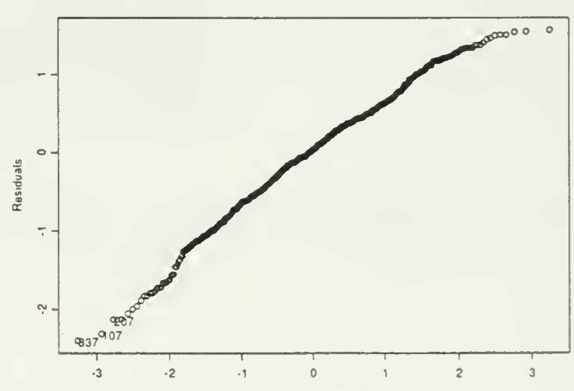

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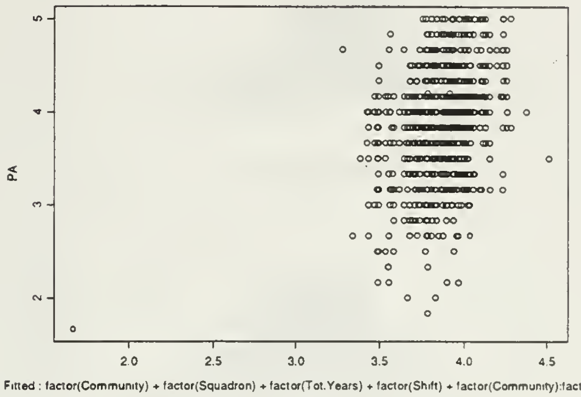
APPENDIX S. REDUCED TWO FACTOR INTERACTION MODELS

```
Model:
PA ~ factor(Community) + factor(Squadron) + factor(Tot.Years) + factor(Shift) +
factor(Community):factor(Shift)

scale:  0.2751949

                                Df Sum of Sq      RSS       Cp
                         <none>               259.7296 277.8925
              factor(Squadron) 12  8.235337 267.9649 279.5231
             factor(Tot.Years)  6  7.737269 267.4669 282.3274
factor(Community):factor(Shift)  5  5.319236 265.0488 280.4597

Model:
QA ~ factor(Community) + factor(Squadron) + factor(Tot.Years) + factor(Shift) +
factor(Community):factor(Shift)

scale:  0.3641075

                                Df Sum of Sq      RSS       Cp
                         <none>               339.8904 363.9215
              factor(Squadron) 12  12.36975 352.2601 367.5526
             factor(Tot.Years)  6  16.34776 356.2381 375.8999
factor(Community):factor(Shift)  5   8.42356 348.3139 368.7039

Model:
RS ~ factor(Squadron) + factor(Rank) + factor(Tot.Years) + factor(Shop) + factor(Shift) +
factor(Squadron):factor(Shift) + factor(Tot.Years):factor(Shift)

scale:  0.3104461

                                Df Sum of Sq      RSS       Cp
                         <none>               280.7776 317.4103
                  factor(Rank)  6   5.38955 286.1672 319.0745
                  factor(Shop)  9   6.45093 287.2286 318.2732
 factor(Squadron):factor(Shift) 12  11.55724 292.3349 321.5168
factor(Tot.Years):factor(Shift)  5   4.31919 285.0968 318.6250

Model:
RM ~ factor(Squadron) + factor(Rank) + factor(Tot.Years) + factor(Shop) + factor(Shift) +
factor(Squadron):factor(Shift) + factor(Tot.Years):factor(Shift)

scale:  0.2949249

                                Df Sum of Sq      RSS       Cp
                         <none>               255.4226 290.2237
                  factor(Rank)  6   3.99087 259.4134 290.6755
                  factor(Shop)  9   5.55127 260.9738 290.4663
 factor(Squadron):factor(Shift) 12  17.43743 272.8600 300.5829
factor(Tot.Years):factor(Shift)  5   3.57653 258.9991 290.8510


Model:
CC ~ factor(Community) + factor(Squadron) + factor(Rank) + factor(Tot.Years) +
factor(Shift) + factor(Community):factor(Shift) + factor(Squadron):factor(Shift) +

    factor(Rank):factor(Shift) + factor(Tot.Years):factor(Shift)

scale:  0.3595374

                                Df Sum of Sq      RSS       Cp
                         <none>               324.3285 364.5967
factor(Community):factor(Shift)  0  0.000000 324.3285 364.5967
 factor(Squadron):factor(Shift)  7  5.543296 329.8718 365.1065
     factor(Rank):factor(Shift)  5  4.227122 328.5556 365.2285
factor(Tot.Years):factor(Shift)  5  5.275932 329.6045 366.2773
```

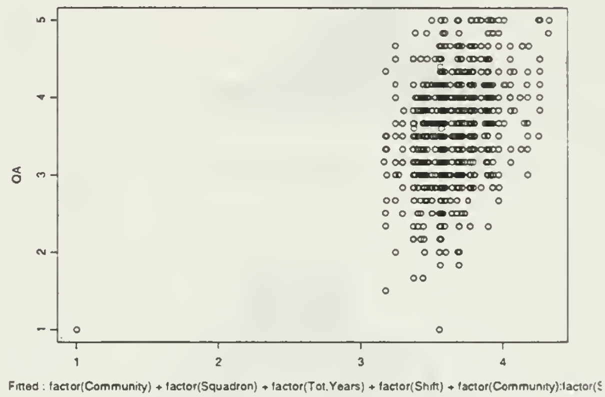
```
Model:
CR ~ factor(Community) + factor(Rank) + factor(Tot.Years) + factor(Shift) +
factor(Community):factor(Shift) + factor(Rank):factor(Shift) + factor(Tot.Years):
    factor(Shift)

scale:  0.4254993

                                 Df Sum of Sq      RSS       Cp
                          <none>              393.4122 424.8992
factor(Community):factor(Shift)   6  9.058145 402.4703 428.8513
     factor(Rank):factor(Shift)   5  7.047982 400.4602 427.6921
factor(Tot.Years):factor(Shift)   5  7.483000 400.8952 428.1272
```

APPENDIX T. REDUCED TWO FACTOR INTERACTION MODELS: SCATTERPLOTS WITH SUPERIMPOSED REGRESSION LINE

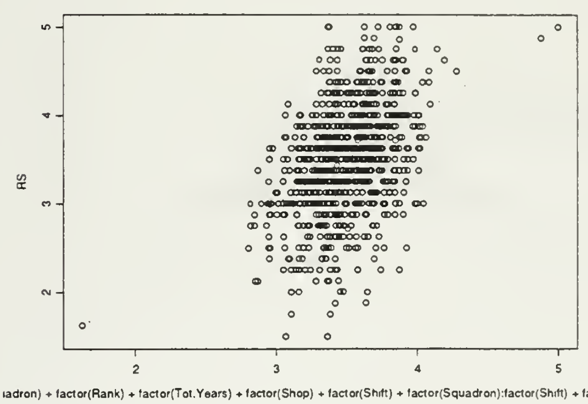
PA



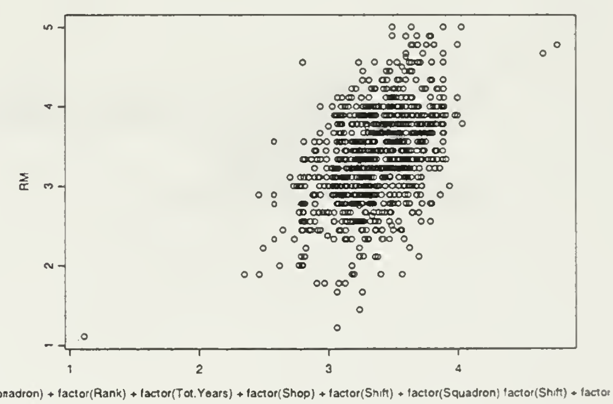
QA



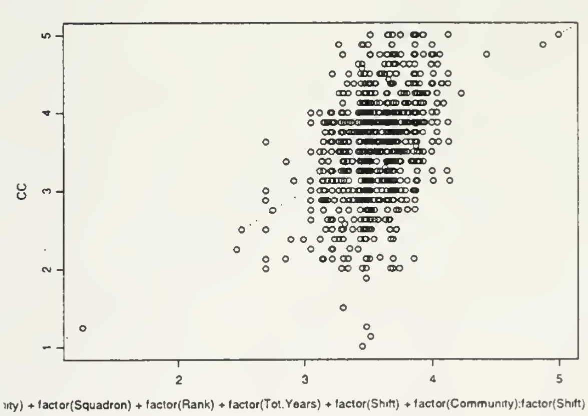
RS



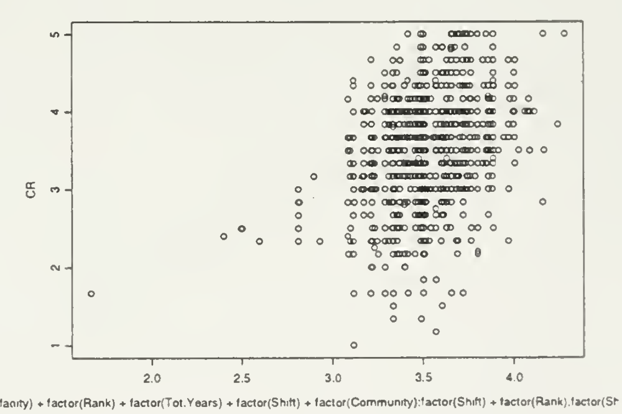
RM



CC



CR



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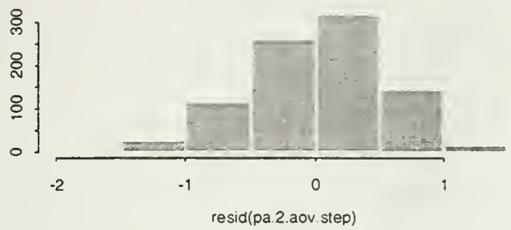
APPENDIX U. REDUCED TWO FACTOR INTERACTION MODELS: HISTOGRAMS OF RESIDUALS

PA



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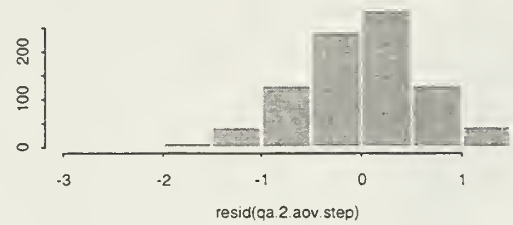
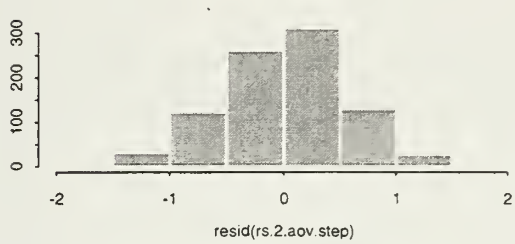


RS



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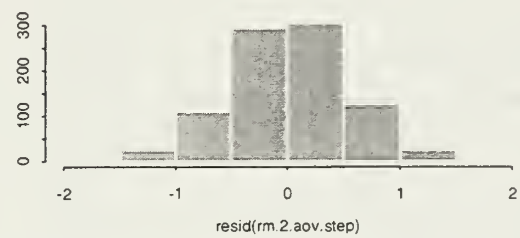

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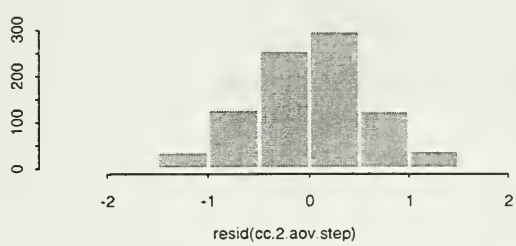

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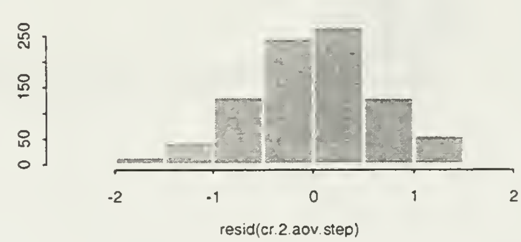

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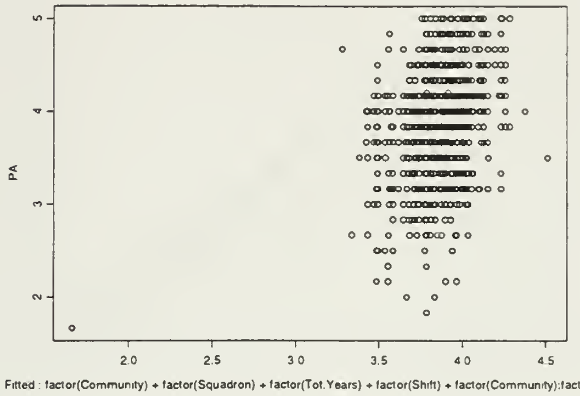
APPENDIX V. REDUCED TWO FACTOR INTERACTION MODELS: RESIDUALS VERSUS FITTED VALUES

PA



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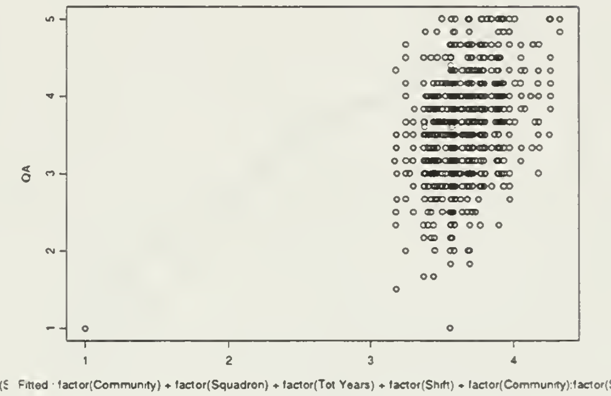

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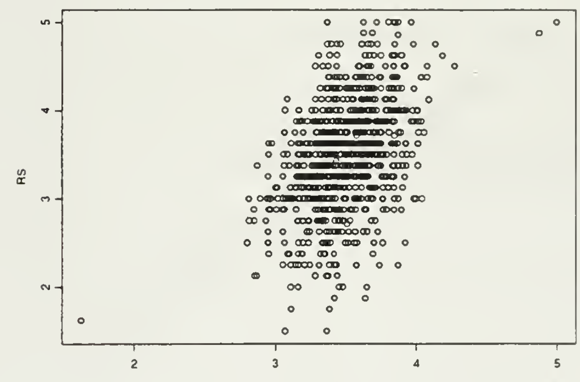

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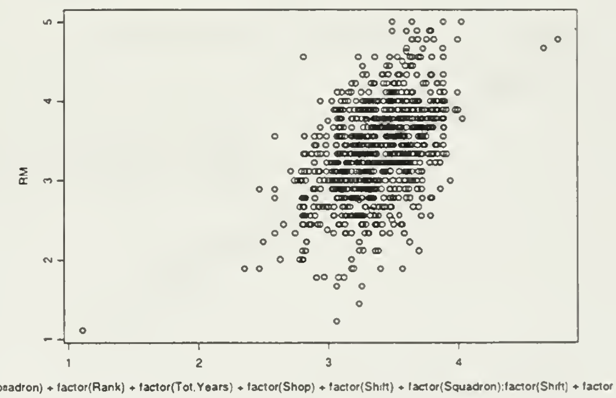

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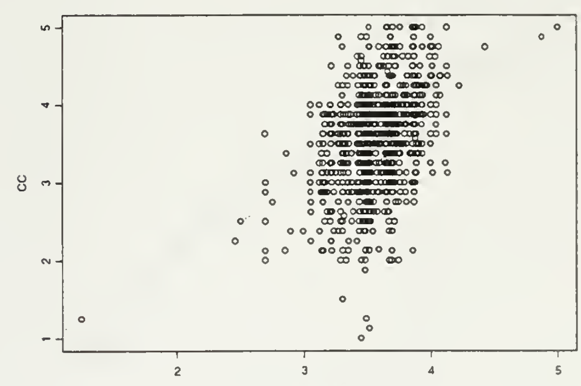

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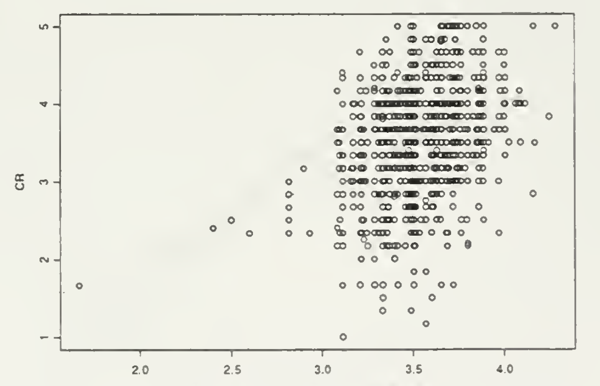

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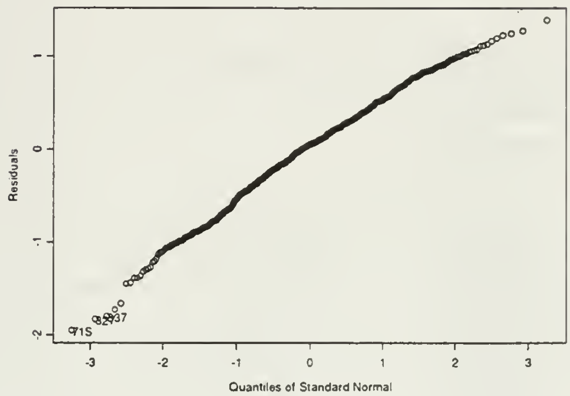
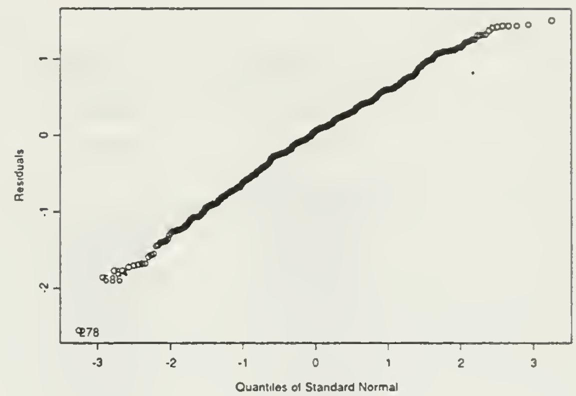
APPENDIX W. REDUCED TWO FACTOR INTERACTION MODELS: QQ-PLOTS

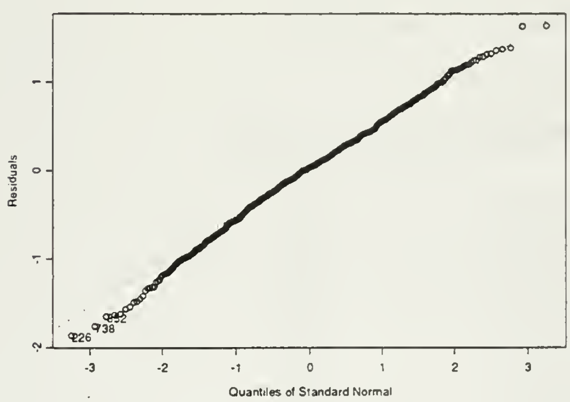
PA



QA



RS



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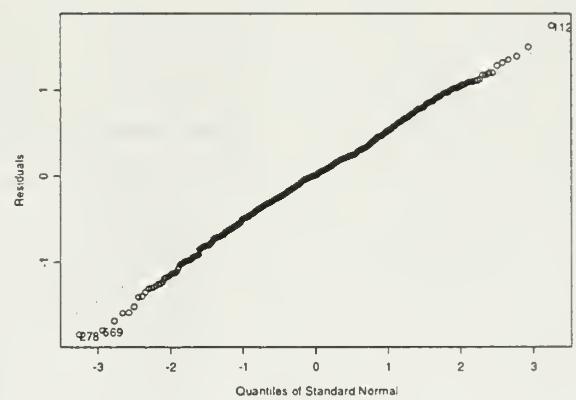

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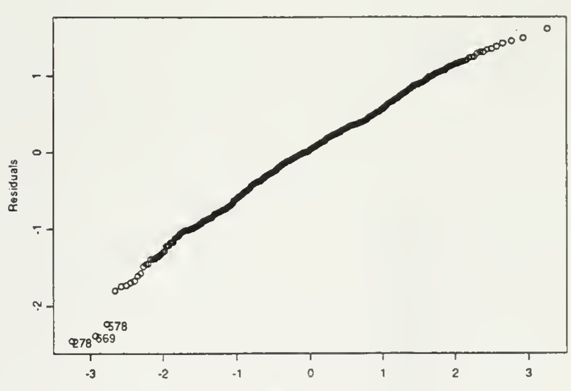

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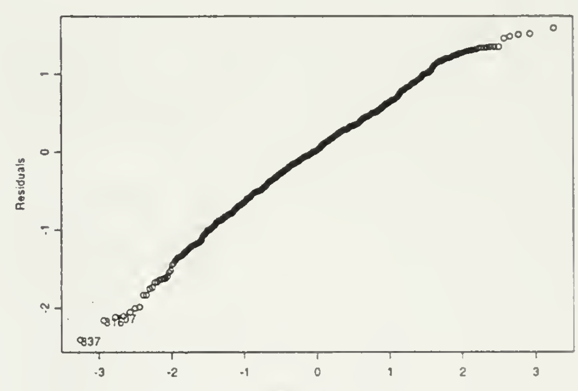

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APPENDIX X. COMPARISONS ON MODELS USING ANOVA

The values listed in the following tables are the probabilities that the models are equivalent. Values printed in bold type indicate similar models.

Component	Simple vs Two Factor Interaction	Simple vs. Reduced Simple	Simple vs. Reduced Two Factor Interaction
PA	0.00316	**0.37994**	**0.99999**
QA	0.00657	**0.17934**	**0.99990**
RS	0.00174	0.04694	0.00029
RM	0.00730	**0.09862**	1.86442e-7
CC	0.00156	**0.20517**	0.00001
CR	0.00580	0.03360	**0.10600**

Component	Two Factor Interaction vs. Reduced Simple	Two Factor Interaction vs. Reducd Two Factor Interaction
PA	0.00324	0.00788
QA	0.00488	0.01596
RS	0.00087	0.01474
RM	0.00470	**0.14662**
CC	0.00121	0.02202
CR	0.00200	0.02111

Component	Reduced Simple vs. Reduced Two Factor Interaction
PA	0.00752
QA	0.00120
RS	0.00011
RM	3.50999e-7
CC	0.00008
CR	0.00016

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APPENDIX Y. SUBJECT MATTER EXPERT RECOMMMENDED CHANGES TO MCAS DEMOGRAPHIC FACTORS

Factors currently included in MCAS (no change):

1. Community
2. Squadron
3. Rank
4. Work Center
5. Shift

Items to modify in MCAS:

Total years of aviation maintenance experience (single item)

modified to:

6. Years worked in MOS
7. Years worked outside MOS

Factors to add to MCAS:

education/training level

8. attended an A school
9. highest level of education attained
10. number of maintenance activities assigned to during career

morale/motivation indicators

11. command advanced
12. number of personal awards
13. level of job satisfaction
14. time to attain qualifications
15. past performance on personal evaluations
16. assigned to B tour

other factors

17. Age
18. number of months in current squadron
19. number of deployments
20. supervisory designations earned
21. level of confidence in Maintenance Control Officer

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